

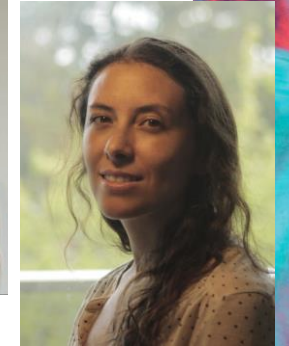


Mechanisms and Models group

Gina Kuperberg

Maria Francisca Alonso





About us - Survey

- Boston, US
- Groningen, Netherlands
- Zurich, Switzerland
- Piscataway, US
- Barcelona, Spain
- Valparaiso, Chile
- New York, US
- Jerusalem, Israel
- Milan, Italy
- Zagreb, Croatia

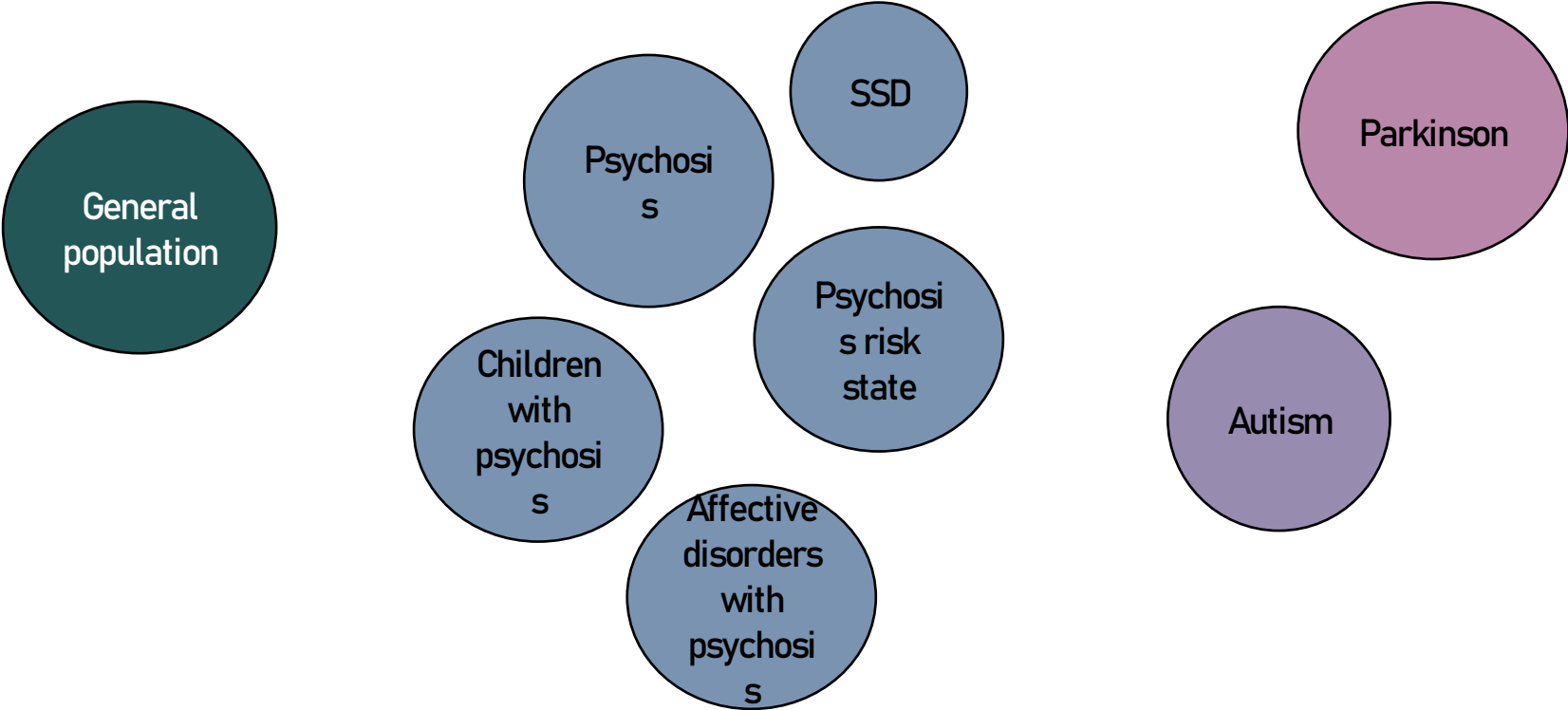


PhD students

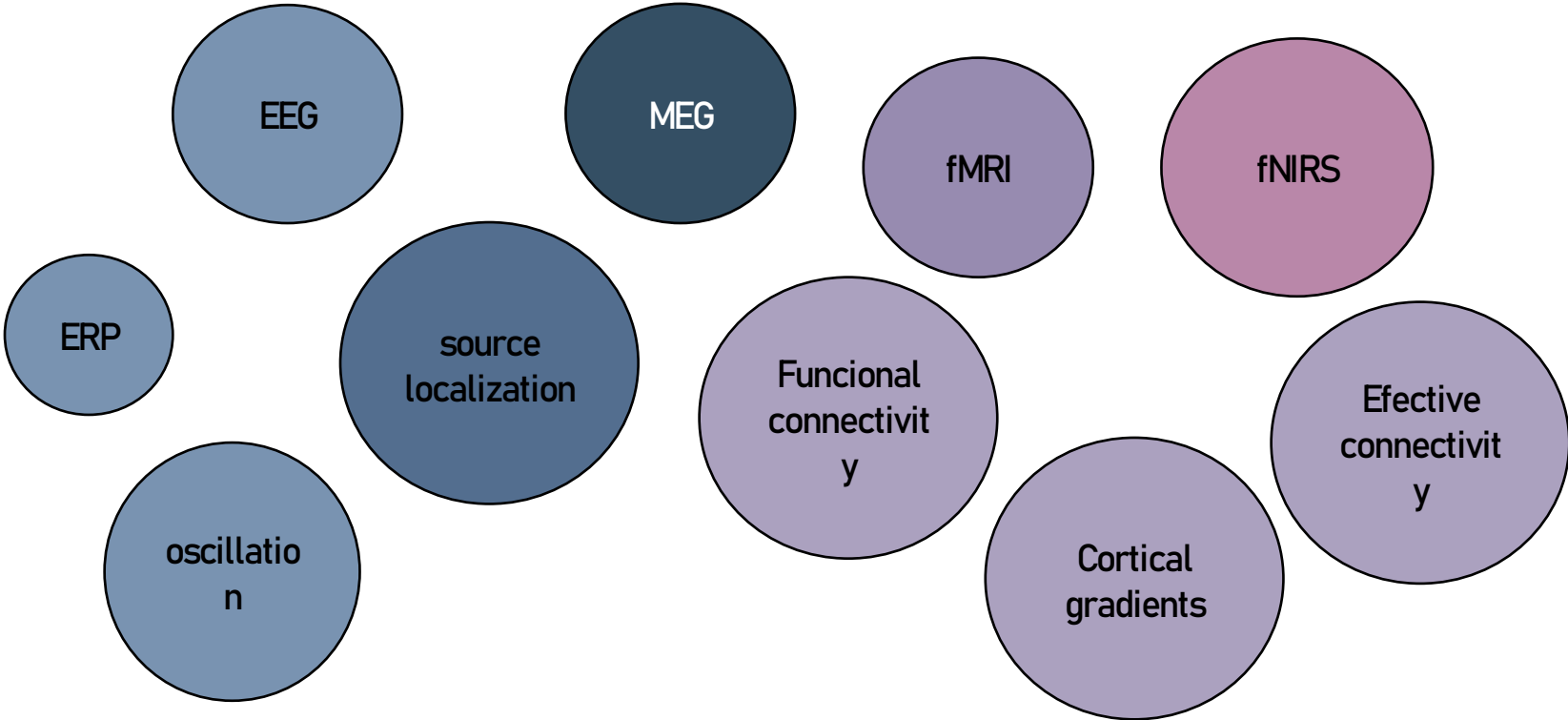
Postdocs

Professors

Please, describe the population of your research



Describe brain measurements that you are using in your research program

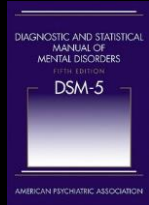


Our aims

- Discussing both theoretical frameworks and empirical methods.
- Collaborate and expand partnerships to enhance shared projects.
- Share pivotal literature and perspectives
- Facilitate international collaboration through exchange visits and fellowship opportunities.
- Mentorships



Why Study Language in Psychosis?



CLINICAL PHENOMENOLOGY

Language disorganization
Auditory verbal hallucinations
Delusions

PSYCHOSOCIAL DYSFUNCTION



Social communication impairments
Includes comprehension impairments

LANGUAGE

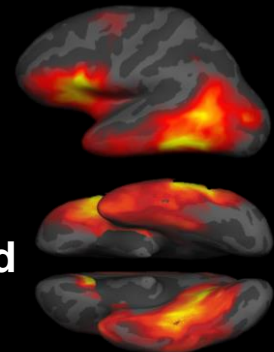
COGNITION & PERCEPTION

Atypicalities in multiple aspects of perception & cognition

NEUROBIOLOGY

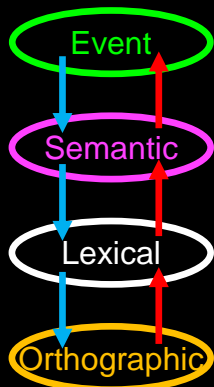
Widespread structural and functional abnormalities

Frontal-temporal disconnection



0.001 0.1 0.05 0.001 [p]

*Kuperberg et al.,
Arch Gen Psych, 2003*



Language Production in Psychosis

Positive Thought Disorder:

~~Poverty of thought~~

Tangentiality/Derailment

Loosening of Associations

Clinically
assessed

Negative Thought Disorder:

Not saying much at all

Prosodic impairments

Sometimes
assessed

Concreteness

Pragmatics

Referential impairments

etc etc

Not routinely
assessed

Language Comprehension in Psychosis

Positive Thought Disorder:

Tangentiality/Derailment
Loosening of Associations

Rarely
Assessed!

Negative Thought Disorder:

Not saying much at all
Prosodic impairments

Sometimes
assessed

Concreteness

Pragmatics

Rarely
Assessed!

Referential impairments

etc etc

Positive Thought Disorder:

Tangentiality/Derailment

Loosening of Associations

Negative Thought Disorder:

Not saying much at all

Prosodic impairments

Concreteness

Pragmatics

Referential impairments

etc etc

Assessment of Positive Thought Disorder: Clinical ratings

Tangentiality & Derailment

“I always liked geography. My last teacher in that subject was Professor August A. He was a man with black eyes. I also like black eyes. There are also blue and grey eyes and other sorts, too...” *Bleuler, 1911/1950*

Loosening of associations / Conceptual disorganization / Illogicality

“If you think you are being wise to send me a bill for money I have already paid, I am in nowise going to do so unless I get the whys and wherefores from you to me. But where the fours have been, then fives will be, and other numbers and calculations and accounts to your no-account....” *Maher, Manschreck, & Molino, 1983*

1 – 2 – 3 – 4 – 5 – 6 – 7

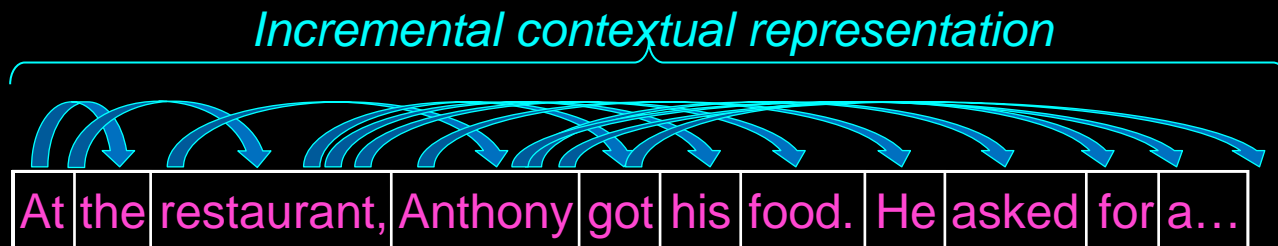
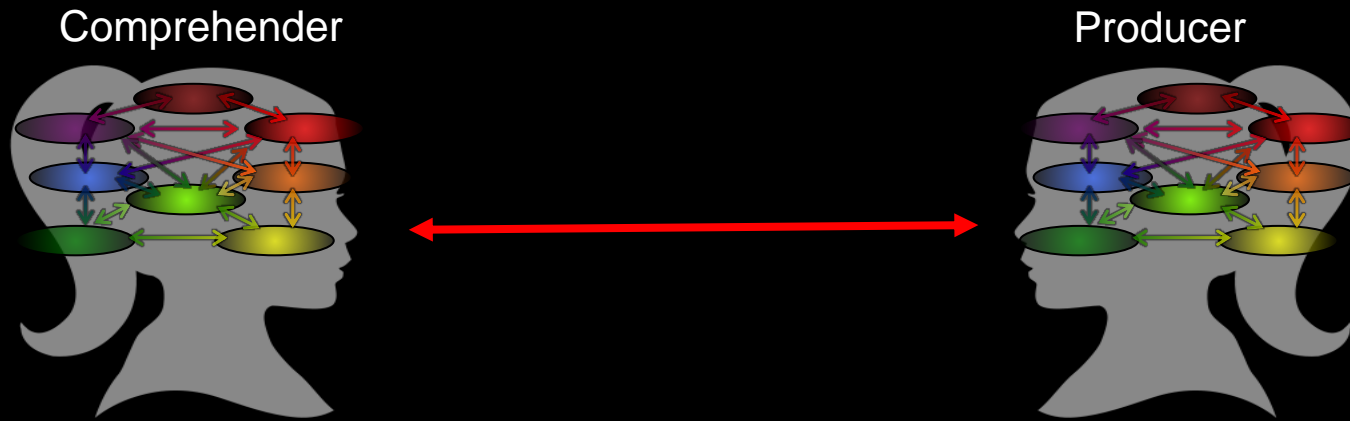


e.g. Andreasen et al, 1979; Liddle et al., 2002

Subjective & time-consuming

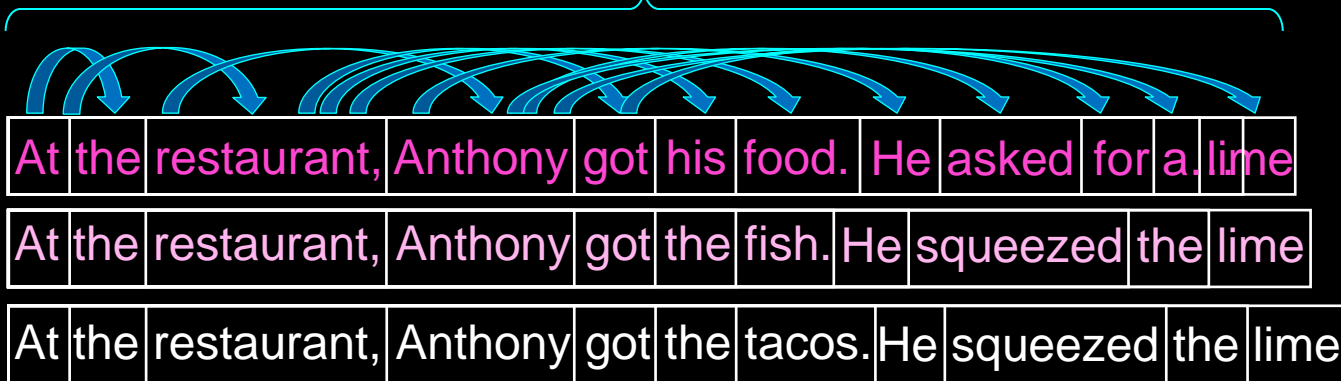
Understanding and Objectively Assessing Positive Thought Disorder

A theoretically informed framework for thinking about Positive Thought Disorder that link production & comprehension

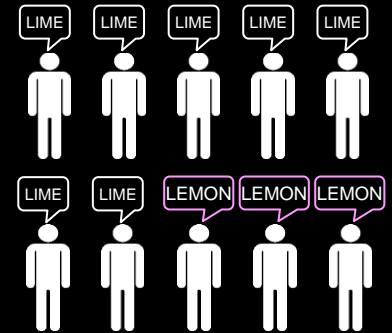


Language Processing is Incremental and Predictive

Incremental contextual representation

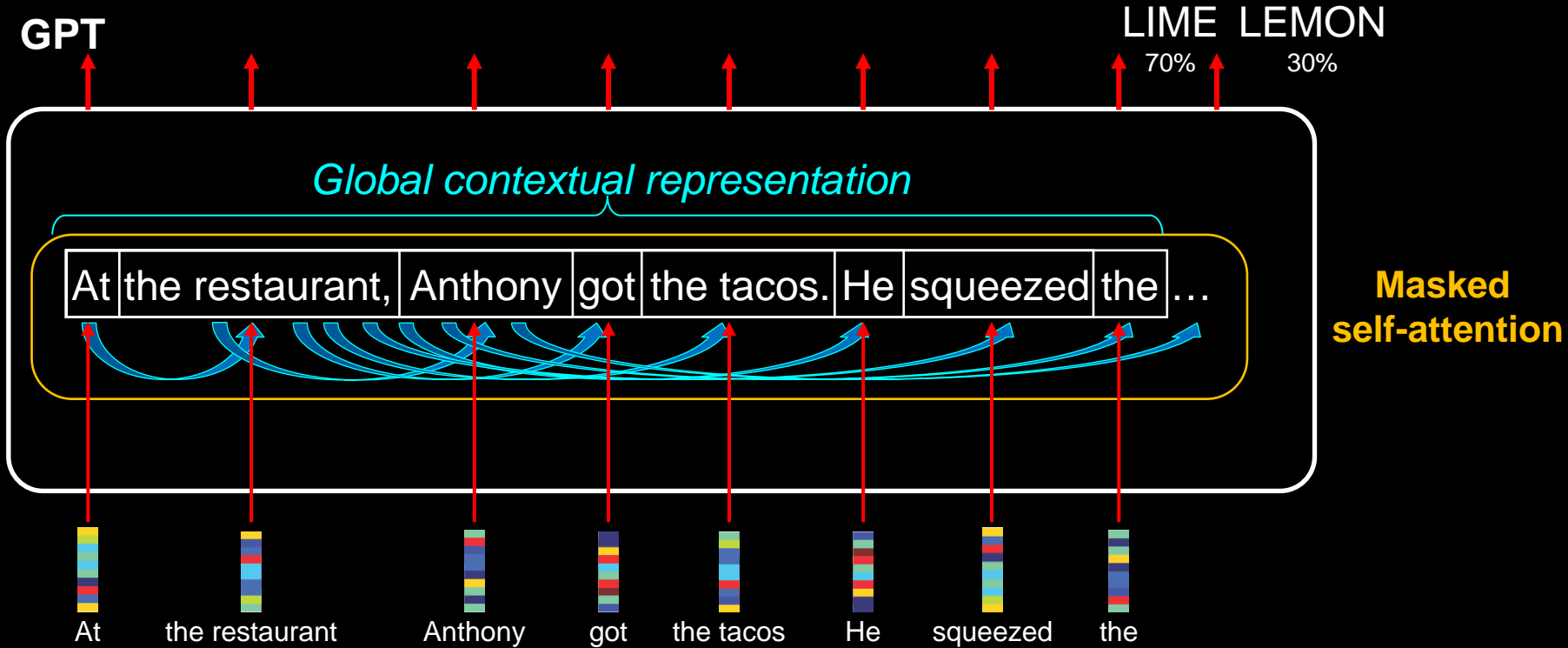


Cloze probability

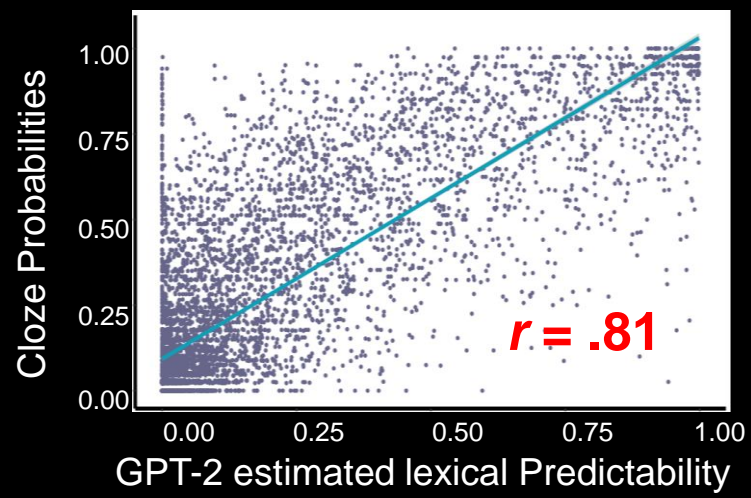
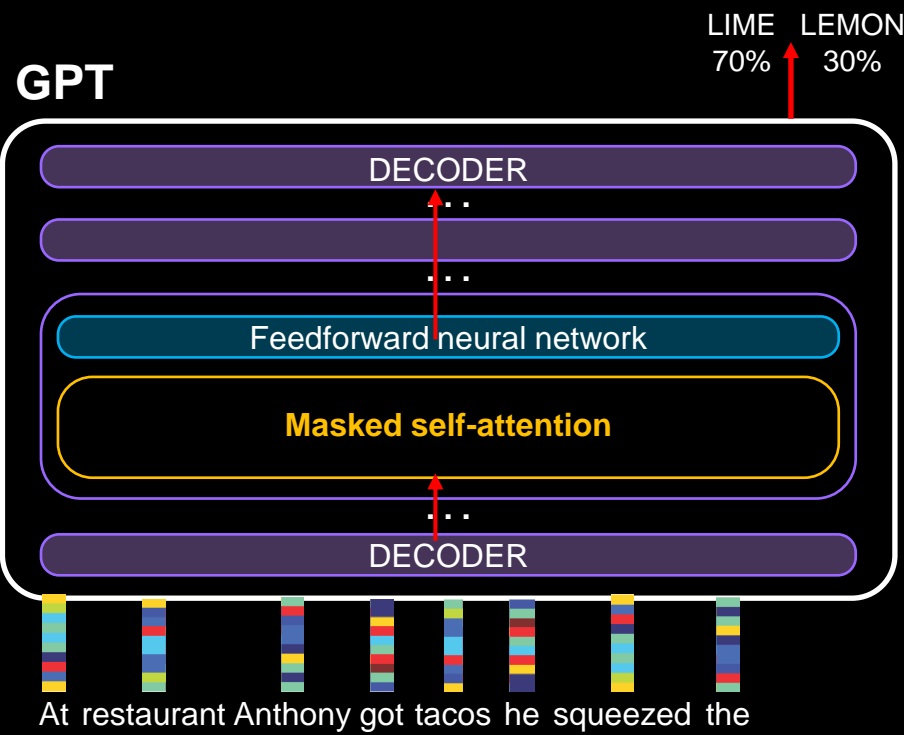


Taylor, Journal Q, 1953

GPT does incremental and predictive language processing



An LLM that is trained to predict upcoming words, based on global contexts is a fantastic tool that can tell us lots about language processing



Sharpe & Kuperberg

An LLM that is trained to predict upcoming words, based on global contexts is a fantastic tool that can tell us lots about thought disorder in schizophrenia

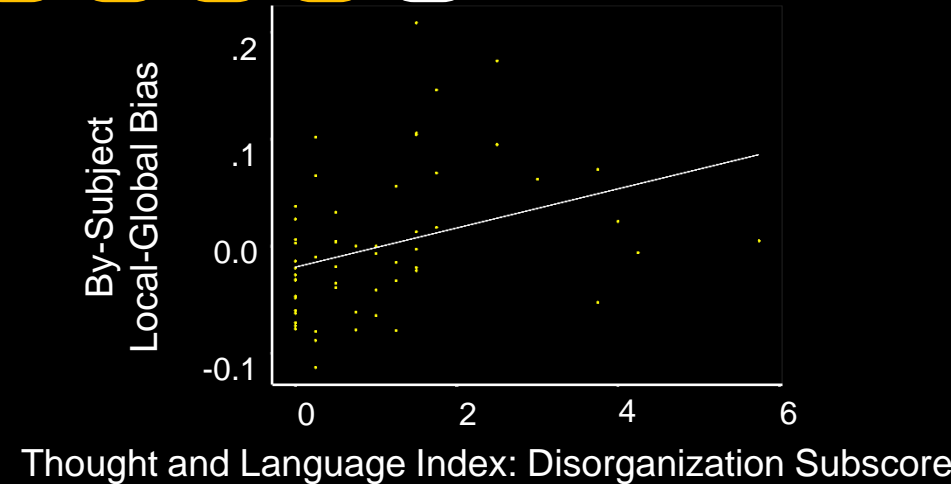
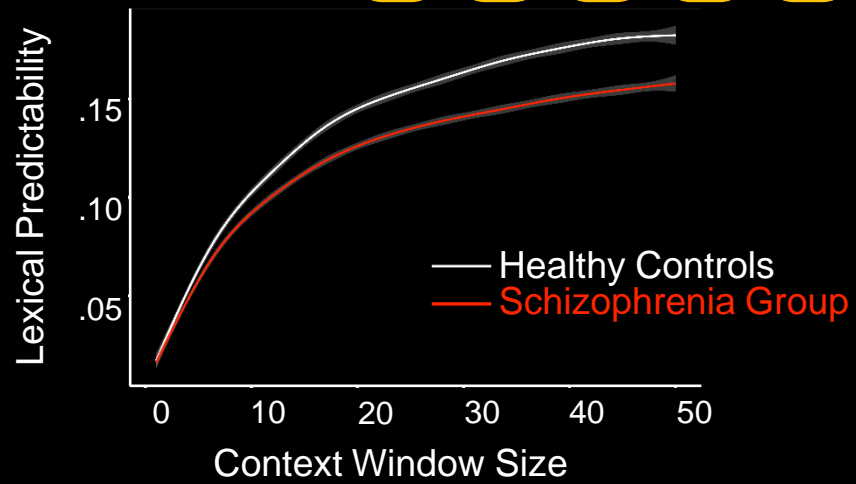
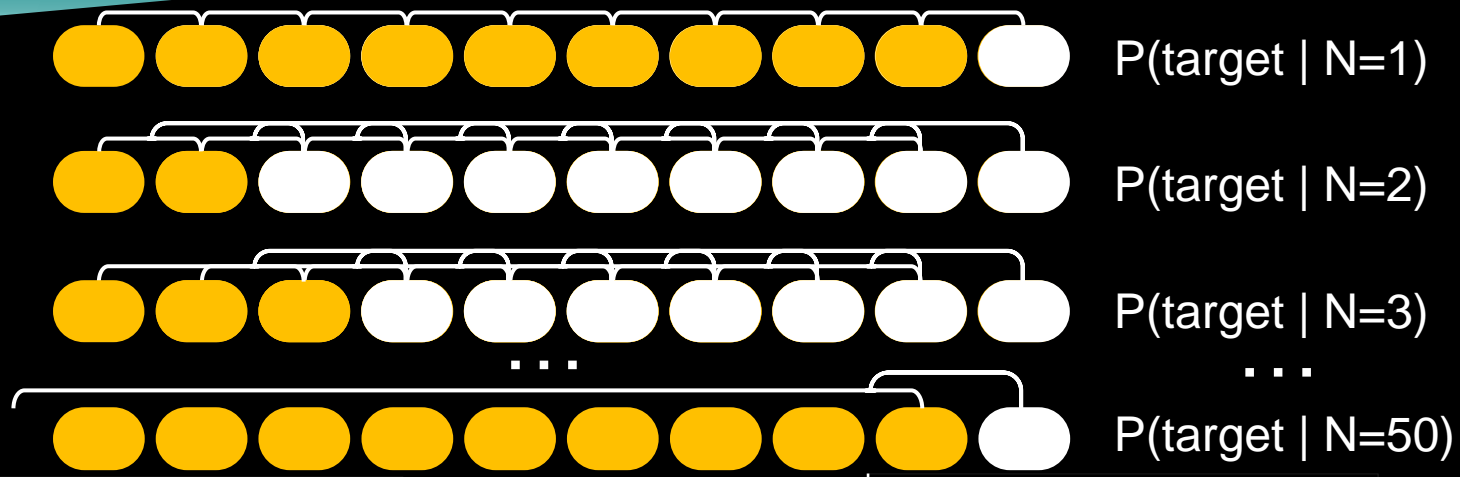


"I always liked geography. My last teacher in that subject was Professor August A. He was a man with black eyes. I also like black eyes. There are also blue and grey eyes and other sorts, too..."

Speech samples
Scz: n=70; controls: n=36



GPT estimates probability based on contexts of increasing window sizes



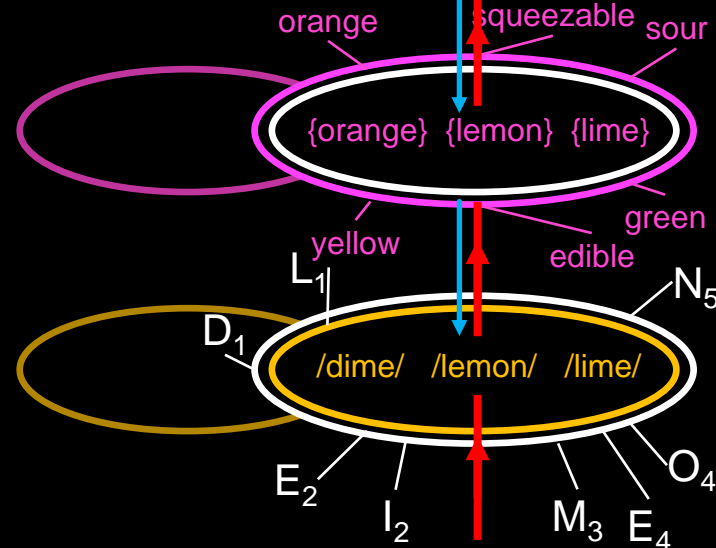
Language: Hierarchically structured information represented at multiple temporal and spatial scales

Current Topic

SITUATION MODEL



EVENT STRUCTURE

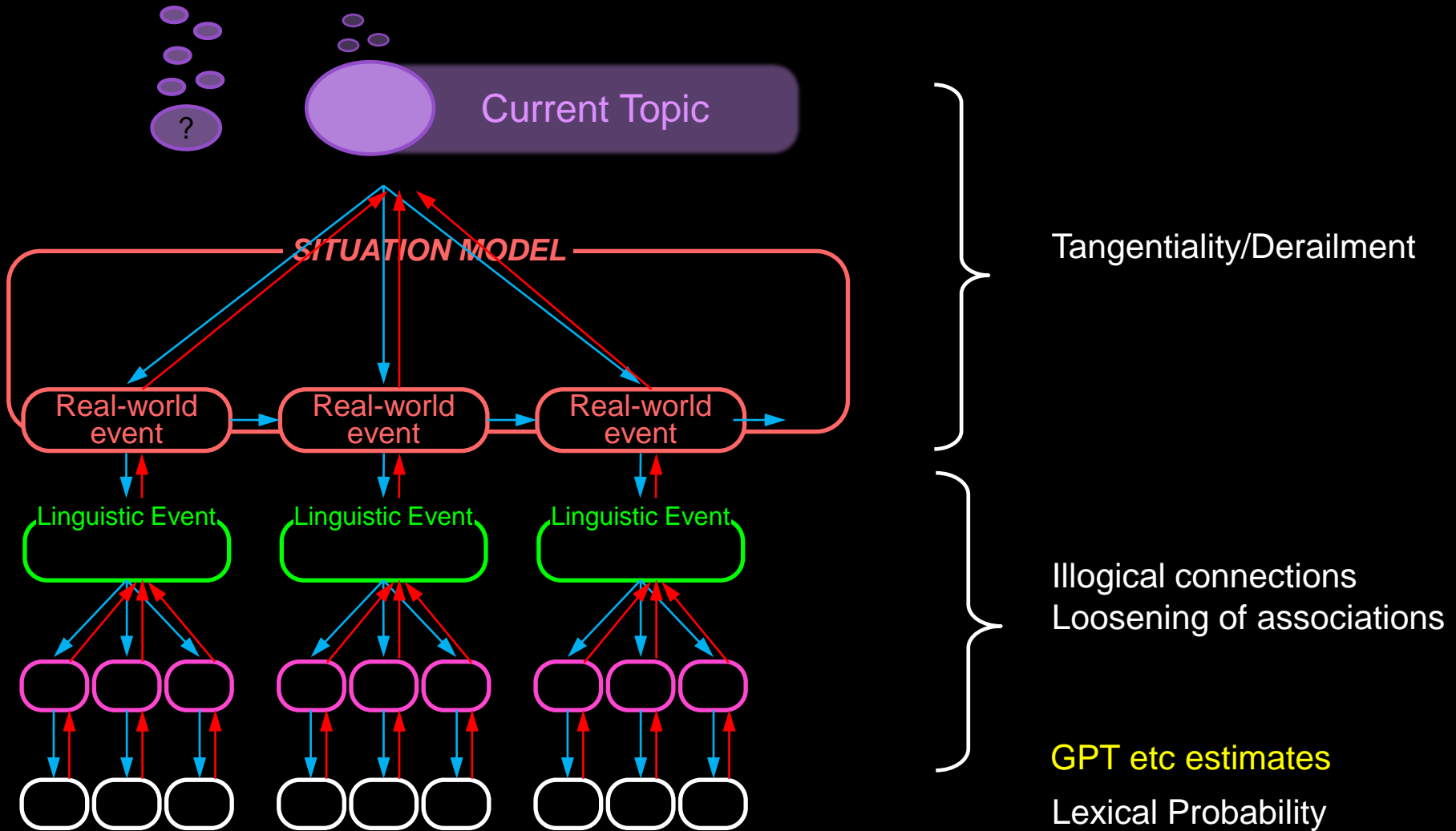


Lexical Probability:
A bottleneck!

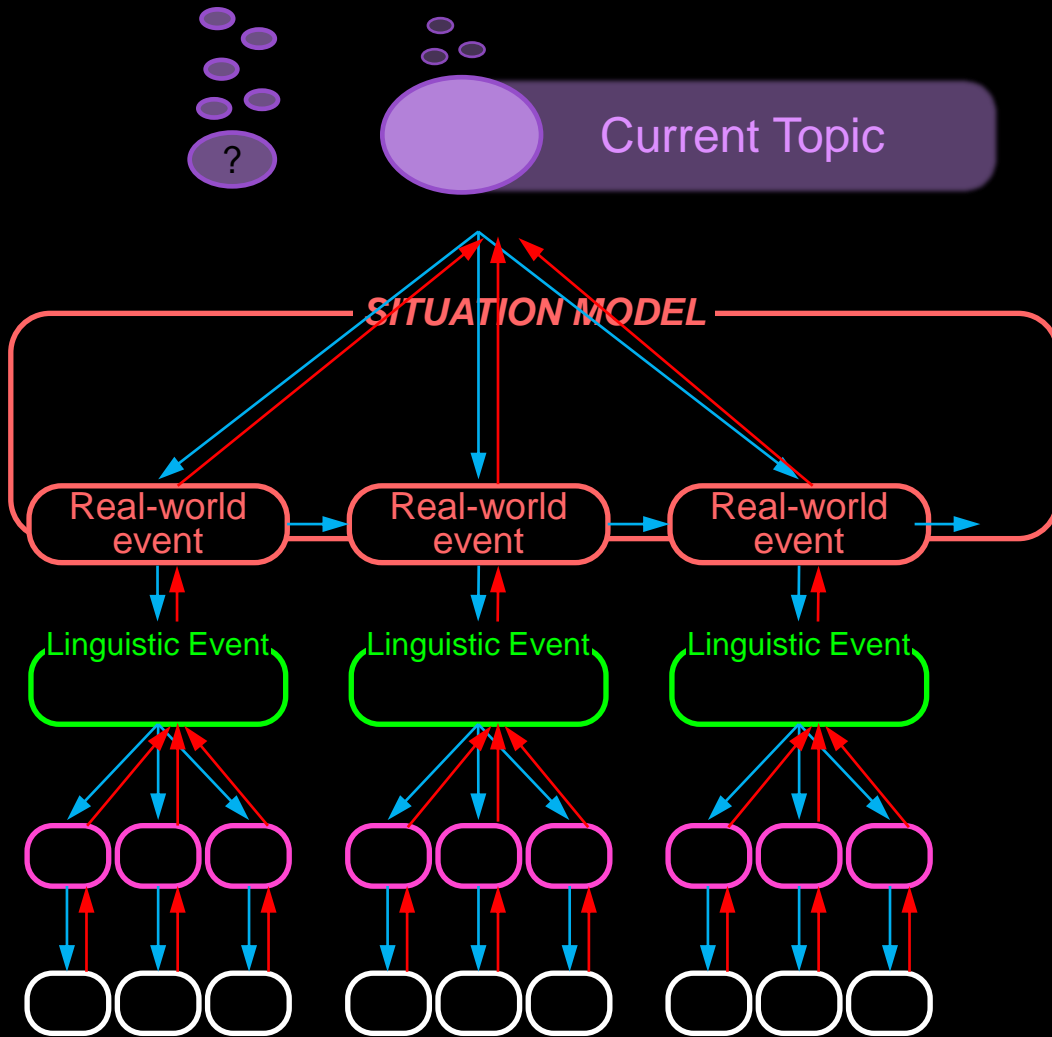
At the restaurant, Anthony got the tacos. Then, he squeezed

the lime

A Theoretically informed Framework for Thinking about Positive Thought Disorder



A Theoretically informed Framework for Thinking about Positive Thought Disorder



Topic Modeling

Tangentiality/Derailment

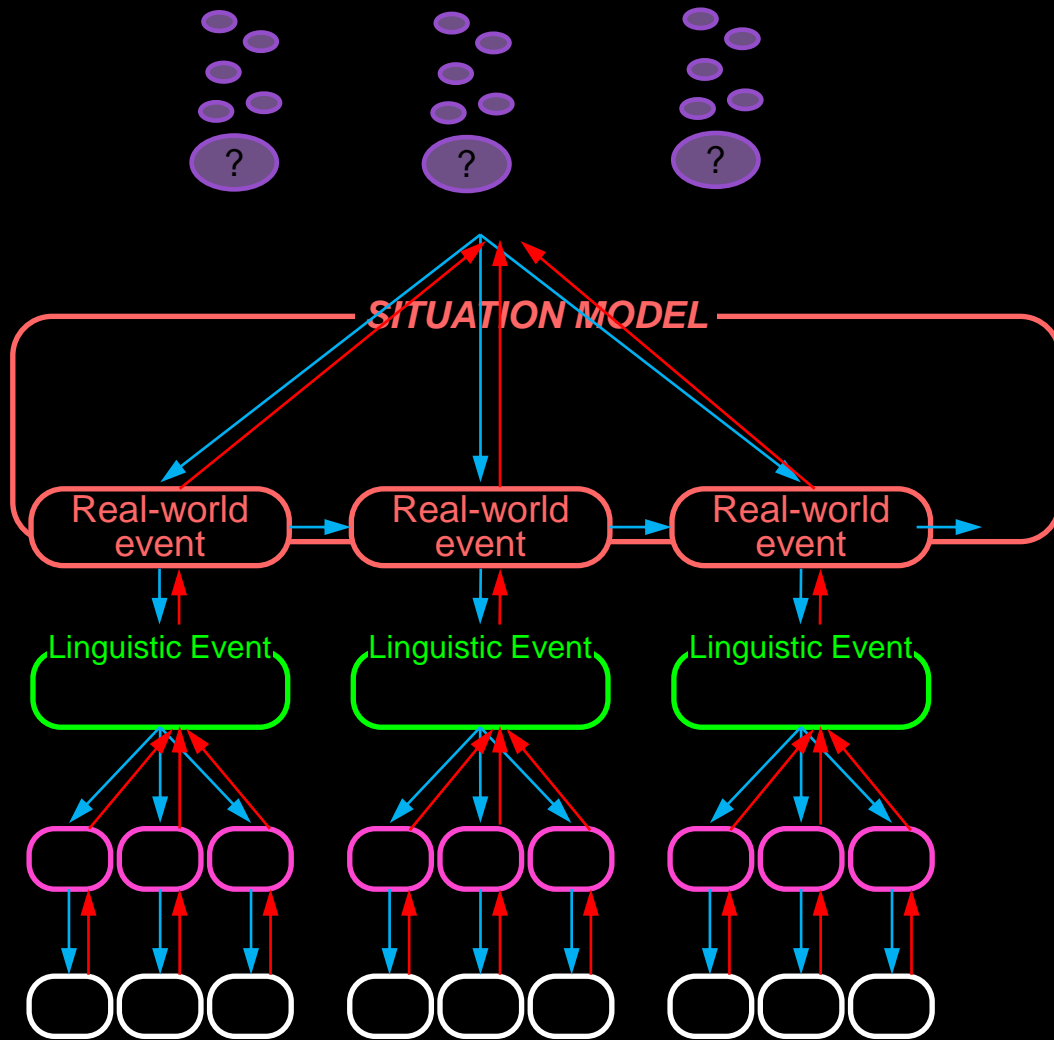
Word2Vec & other similarity measures

Illogical connections
Loosening of associations

GPT etc estimates

Lexical Probability

A Theoretically informed Framework for Thinking about Positive Thought Disorder



?? Reduced topic precision

Topic Modeling

Tangentiality/Derailment

?? Increased semantic association?

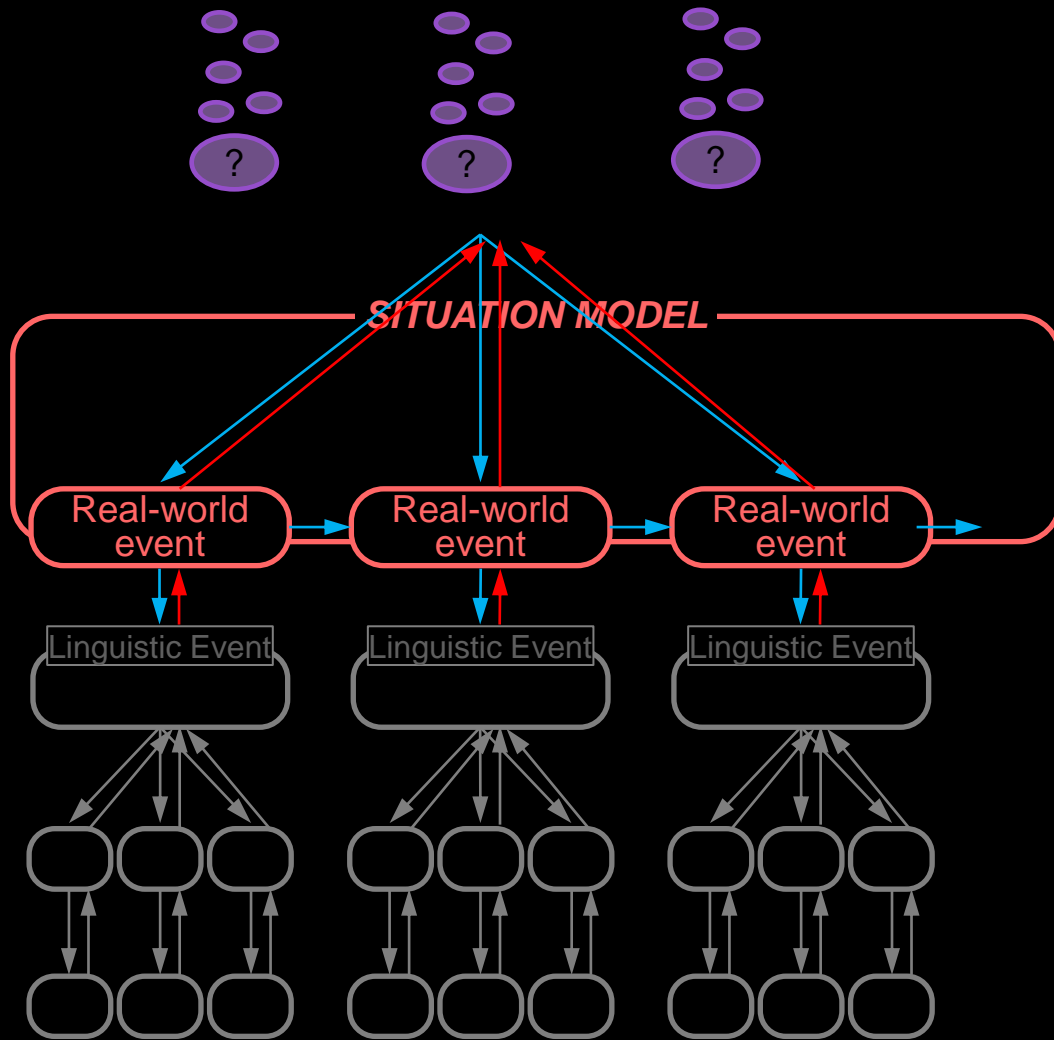
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Illogical connections
Loosening of associations

Selective impairment in use of global vs local context

Lexical Probability

A Theoretically informed Framework for Thinking about Positive Thought Disorder



?? Reduced topic precision

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Tangentiality/Derailment

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Illogical connections

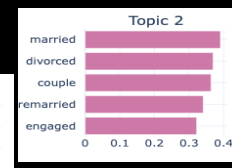
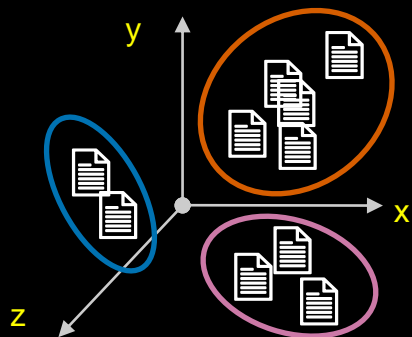
Loosening of associations

Selective impairment in use of global vs local context

Lexical Probability

Topic Entropy using BERTopic

Pre-trained BERTTopics



~1 million Wikipedia pages

Cluster similar documents

2376 "topic" representations

Subdivide into overlapping 20 word snippets & get vector representation

Picture description:

"Alright, so what I see here in the picture is a young girl. She looks to be about, I don't know, maybe ten or eleven? She's out in what looks like a big field..."

Compute similarity with each topic

Snippet 1
Snippet 2

Alright, so what I see here in the picture is a young girl. She looks to be about, I don't...

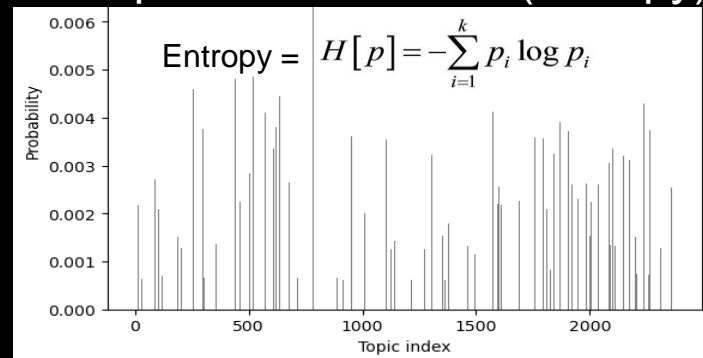
Topic 1	Topic 2	...	Topic 2376
.35	.1203

...so what I see here in the picture is a young girl. She looks to be about, I don't know...

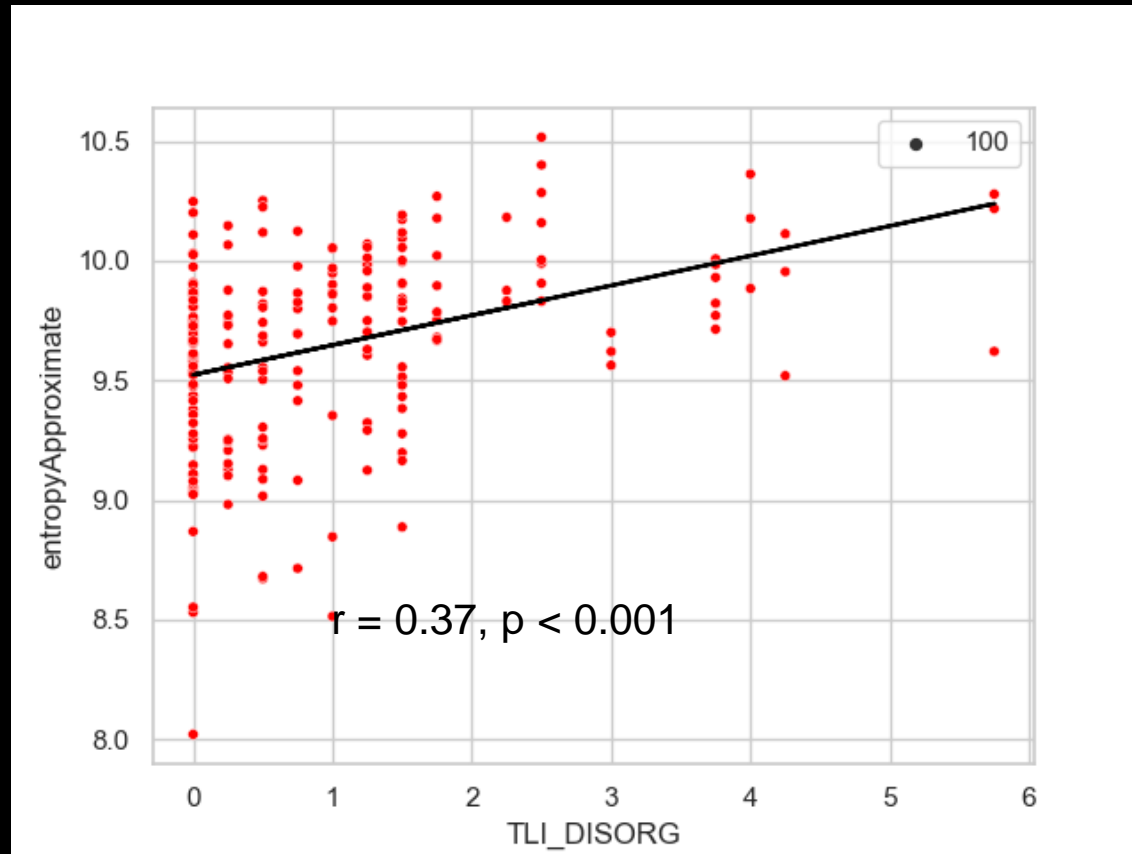
Topic 1	Topic 2	...	Topic 2376
.30	.1401

Sum and normalize

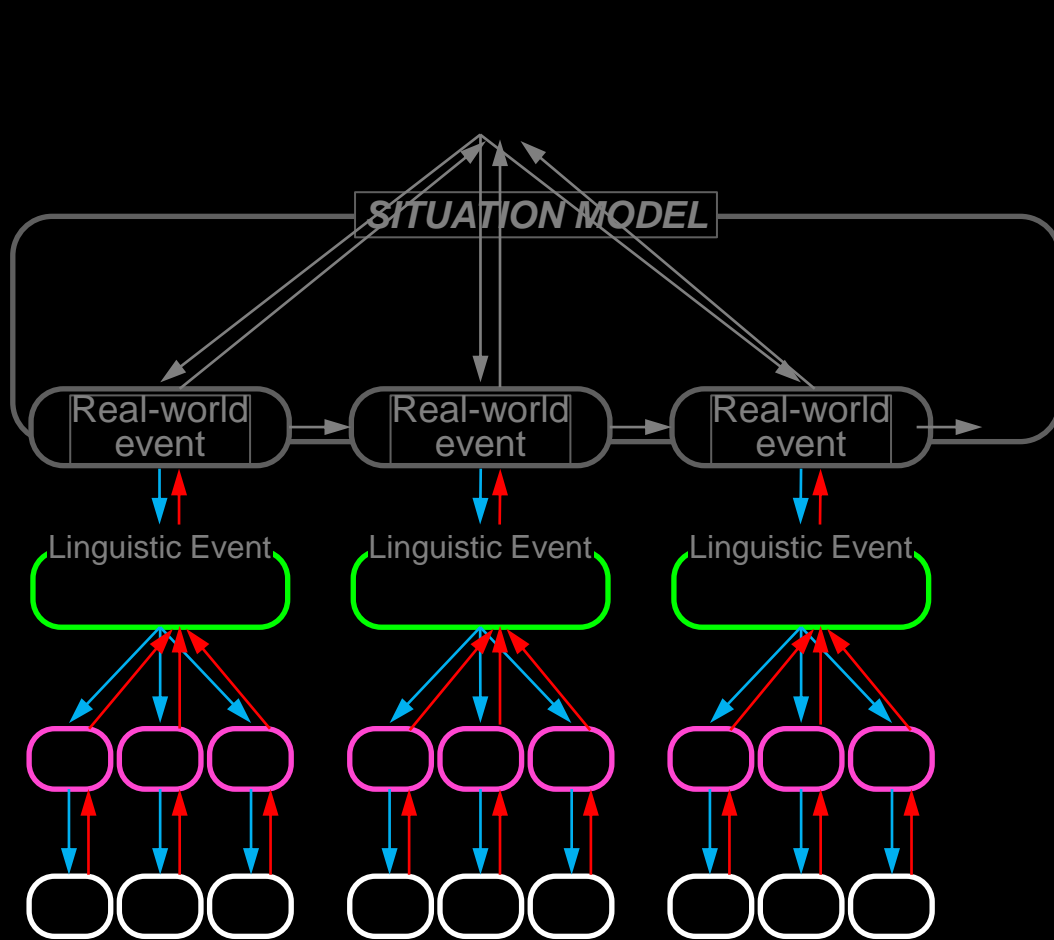
Compute "distribution" (entropy)



Topic entropy predicts Positive Thought Disorder



A Theoretically informed Framework for Thinking about Positive Thought Disorder



Reduced topic precision?

Topic Modeling

Tangentiality/Derailment

?? Increased semantic association

Illogical connections

Loosening of associations

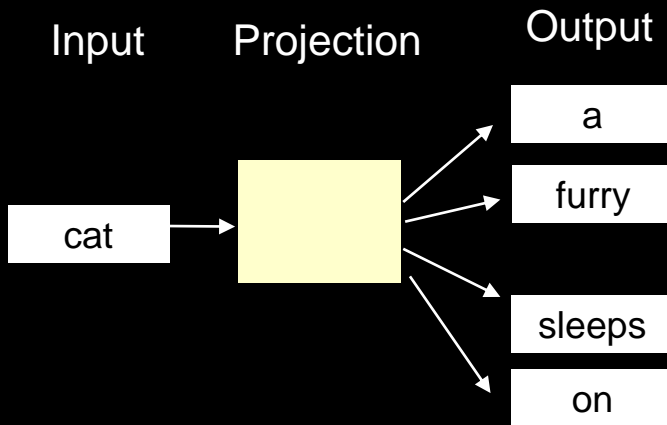
Selective impairment in use of global vs local context

Lexical Probability

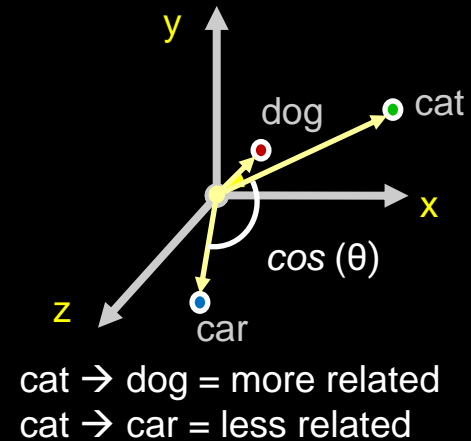
Estimate lexico-semantic similarity using word2vec

Pre-trained Word2Vec representations

Word2Vec word embeddings
trained using neural network



Use cosine similarity to measure the
semantic relatedness of words

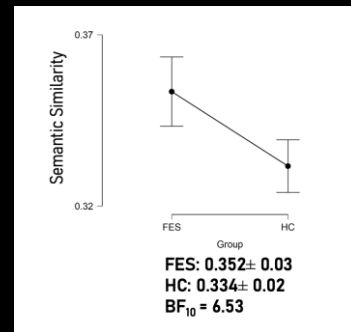


Use word2vec to estimate the semantic relatedness between each produced word and its prior words at increasing distances

“Alright, so what I see here in the picture is a young girl. She looks to be about, I don't know, maybe ten or eleven? She's out in what looks like a big field, full of flowers.”

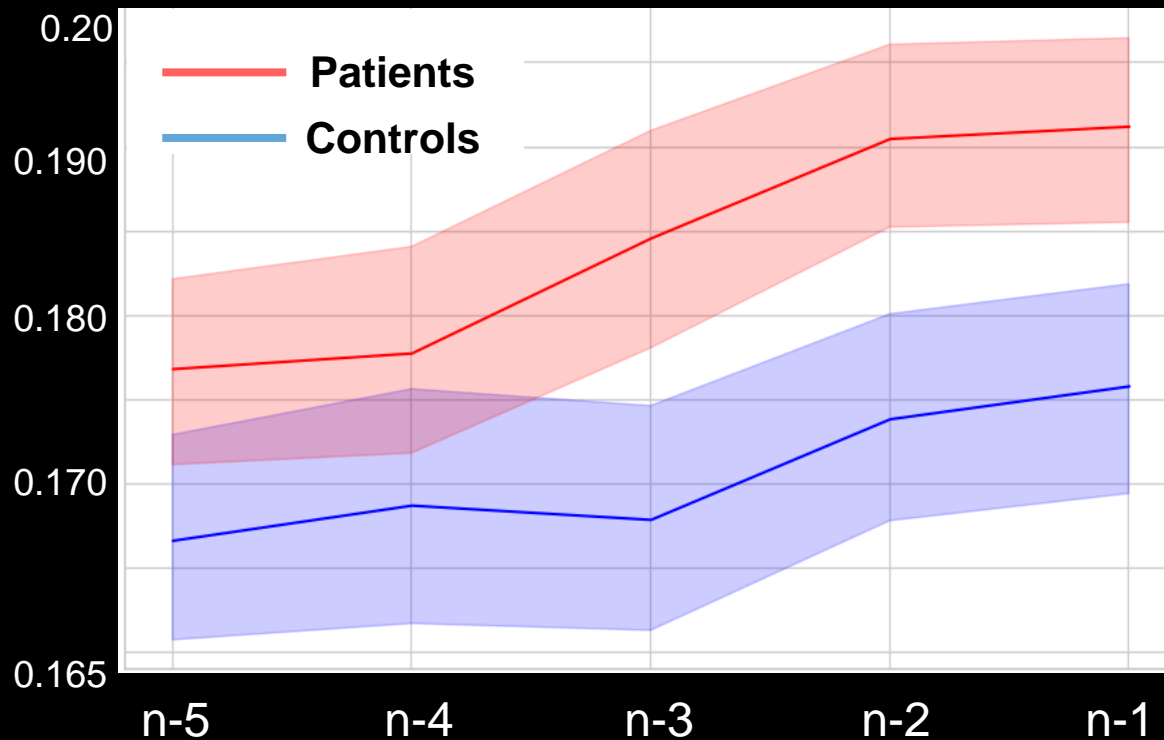


Overdependence on semantic relationships between individual words in schizophrenia

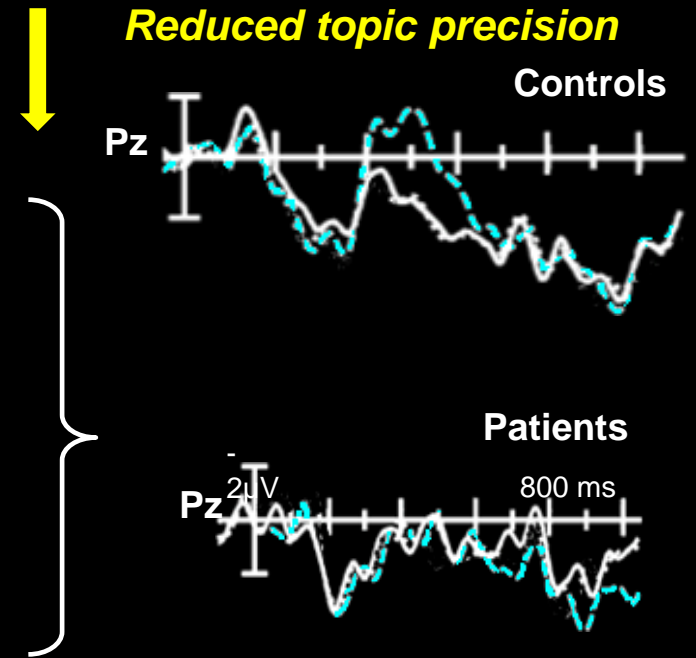
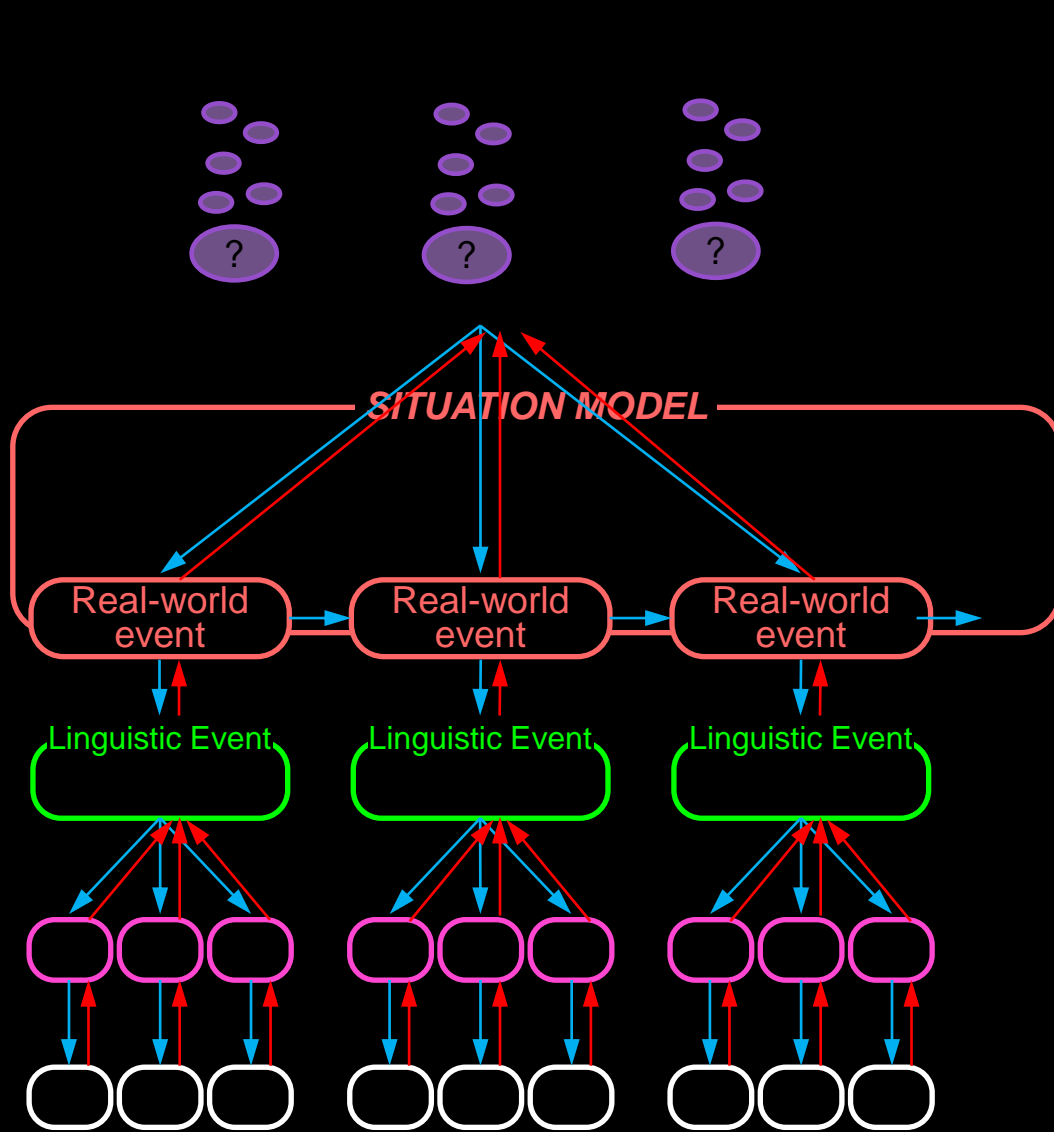


*Alonso et al., 2022
Schizophrenia*

Semantic similarity between word n and its preceding words: overall patients > controls



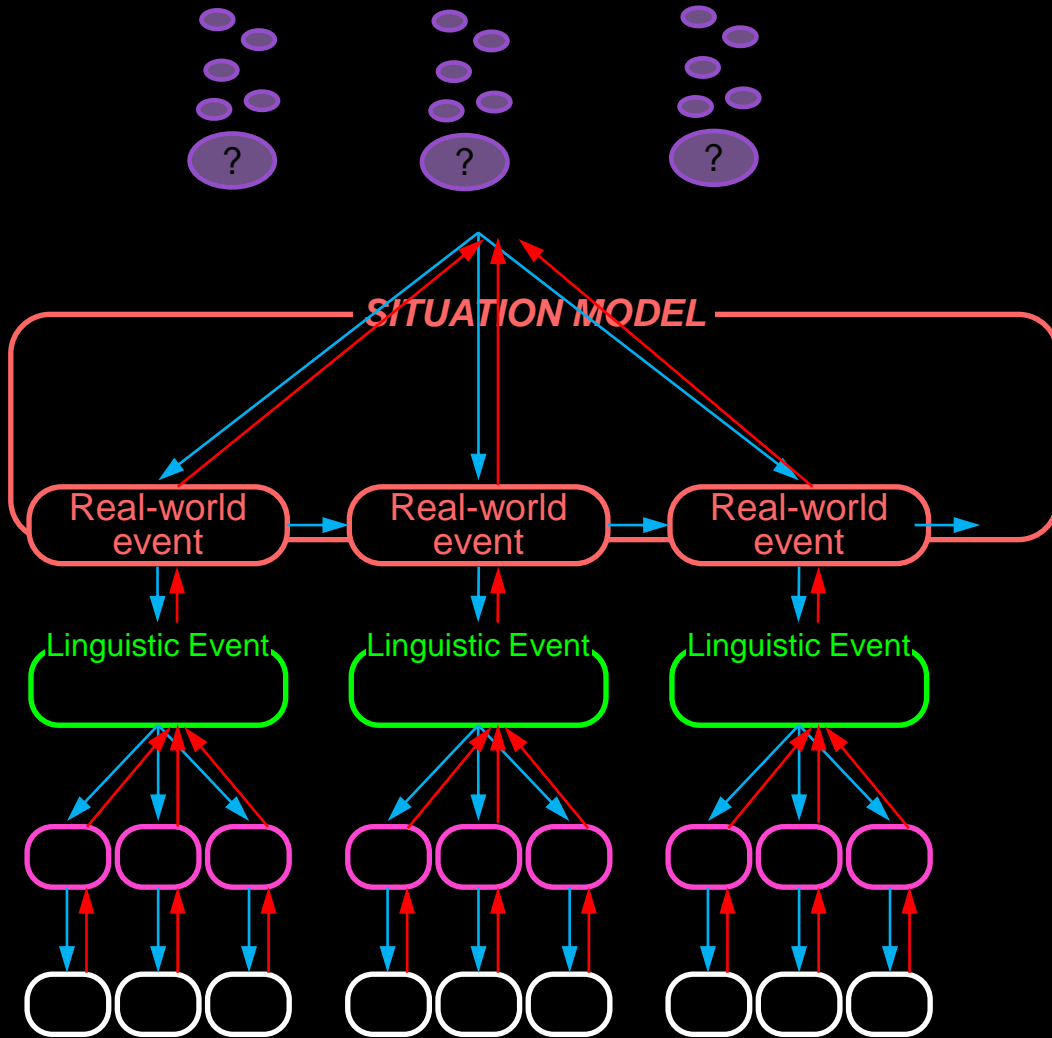
A Theoretically informed Framework for bridging production and comprehension



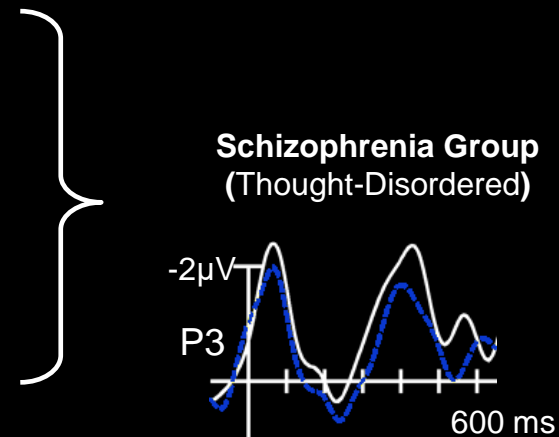
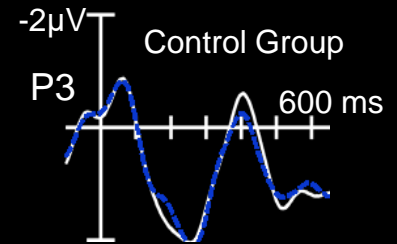
Ditman & Kuperberg, Psychophysiology, 2007

- Discourse incongruous
- Discourse congruous

A Theoretically informed Framework for bridging production and comprehension



↑ **Overdependence semantic associations**

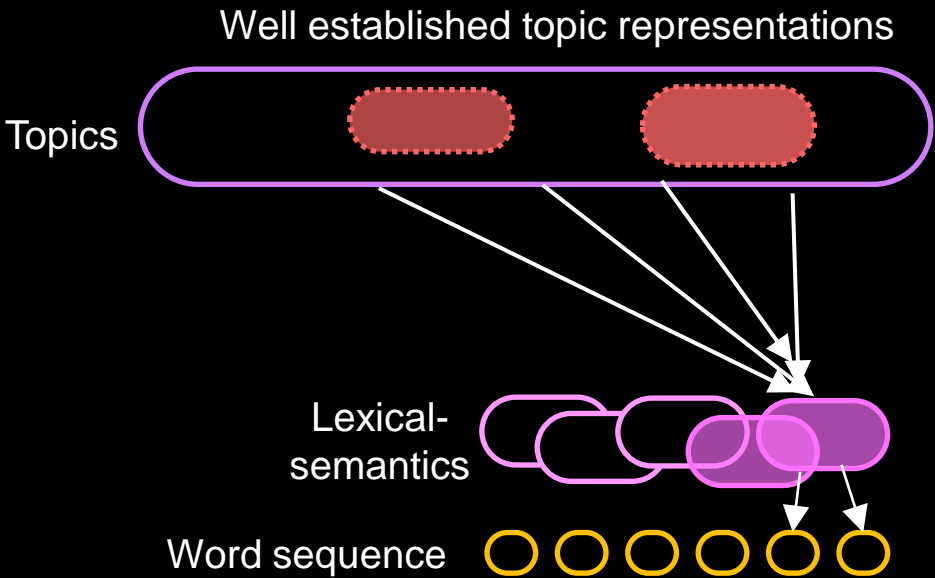


— Non-associated: grass - priest
 --- Indirectly associated: bell - priest

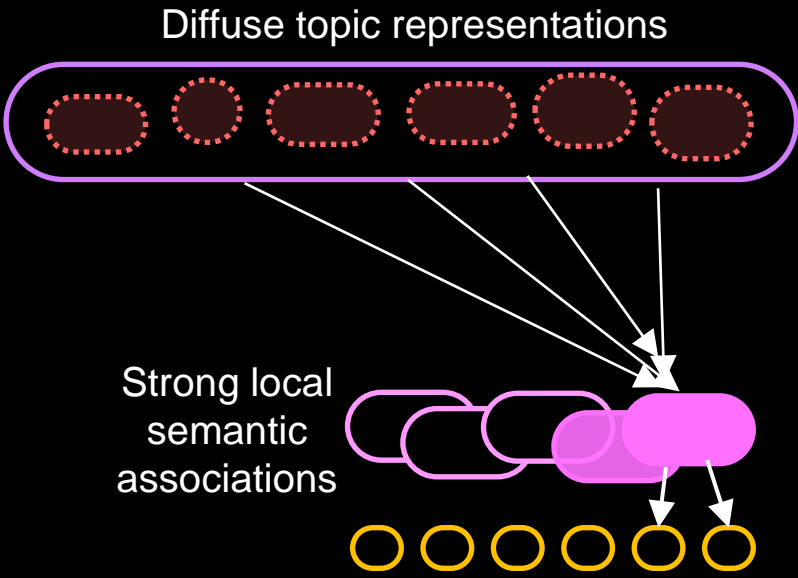
Kreher & Kuperberg, Schiz Bull, 2008

A functional relationship between impaired use of global context and overdependence on semantic associations?

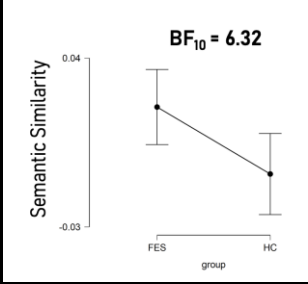
Healthy Adults



Schizophrenia patients

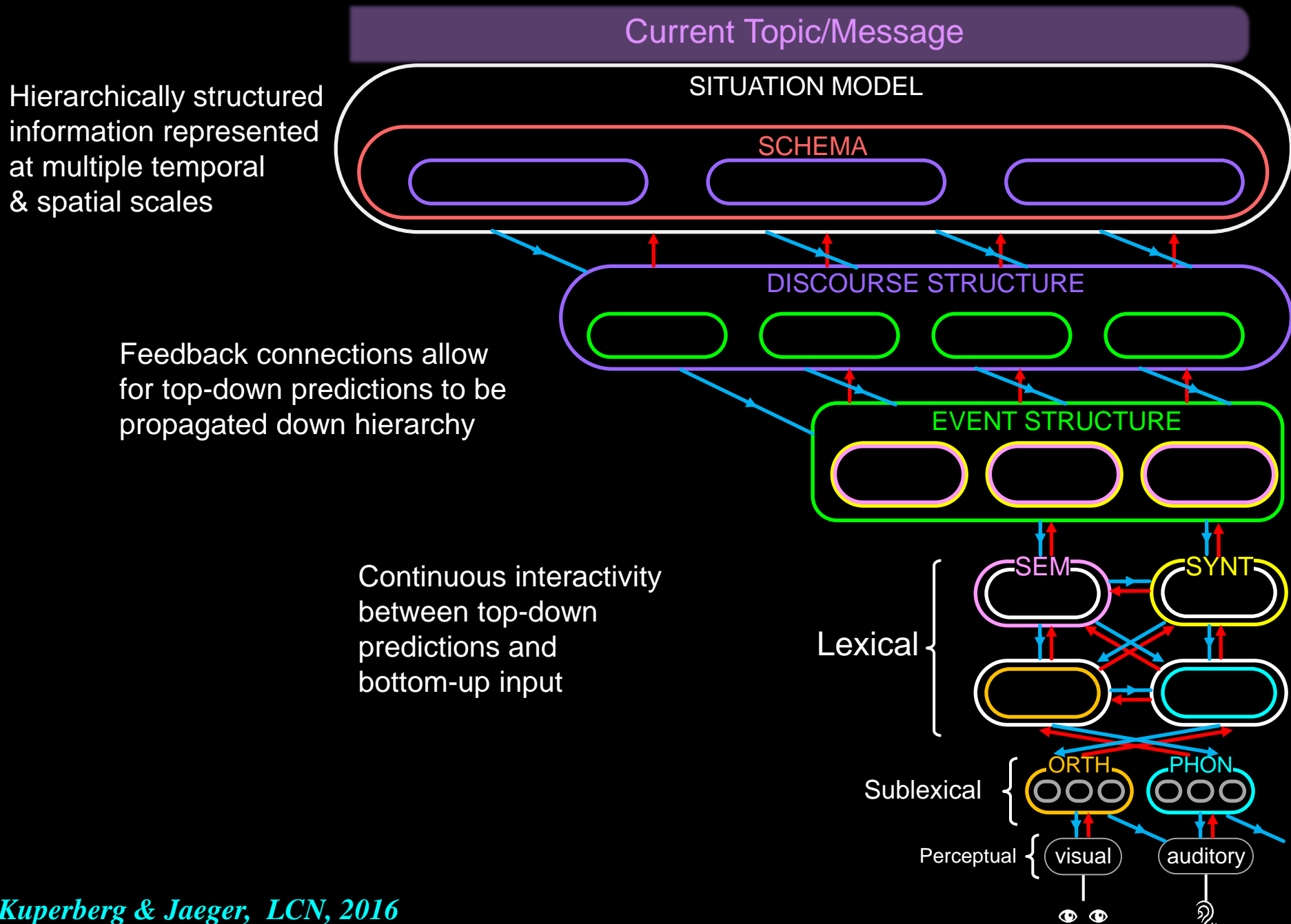


n = 33
FES = 20
HC = 13

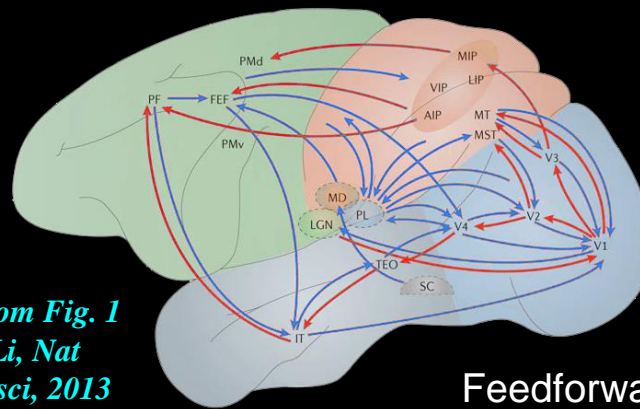


Alonso et al., 2022
Schizophrenia

Language Processing is Predictive, Incremental & *Interactive*

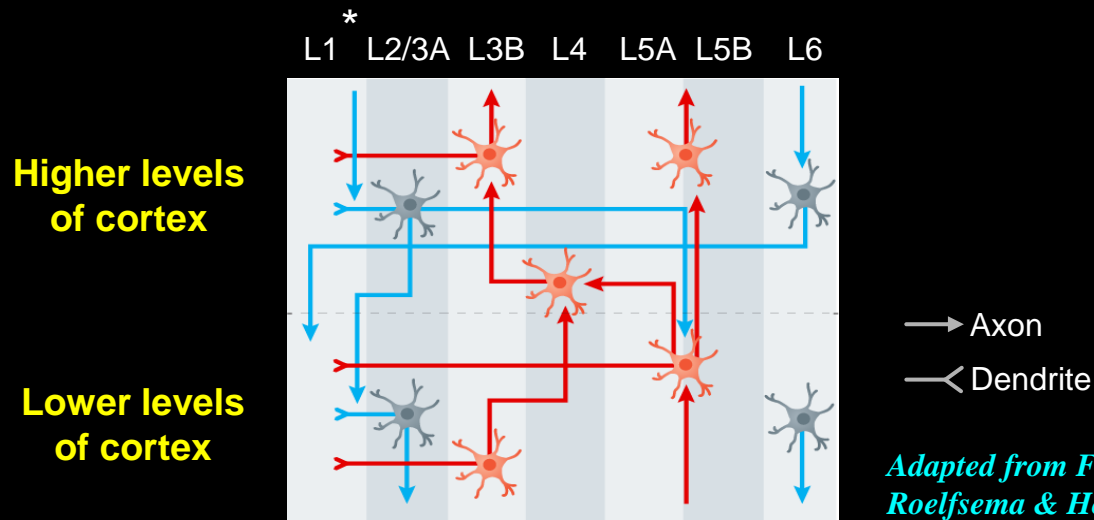


Neurobiological and Computational Mechanism??



Adapted from Fig. 1
 Gilbert & Li, *Nat Rev Neurosci*, 2013

Feedforward →
 Feedback ←

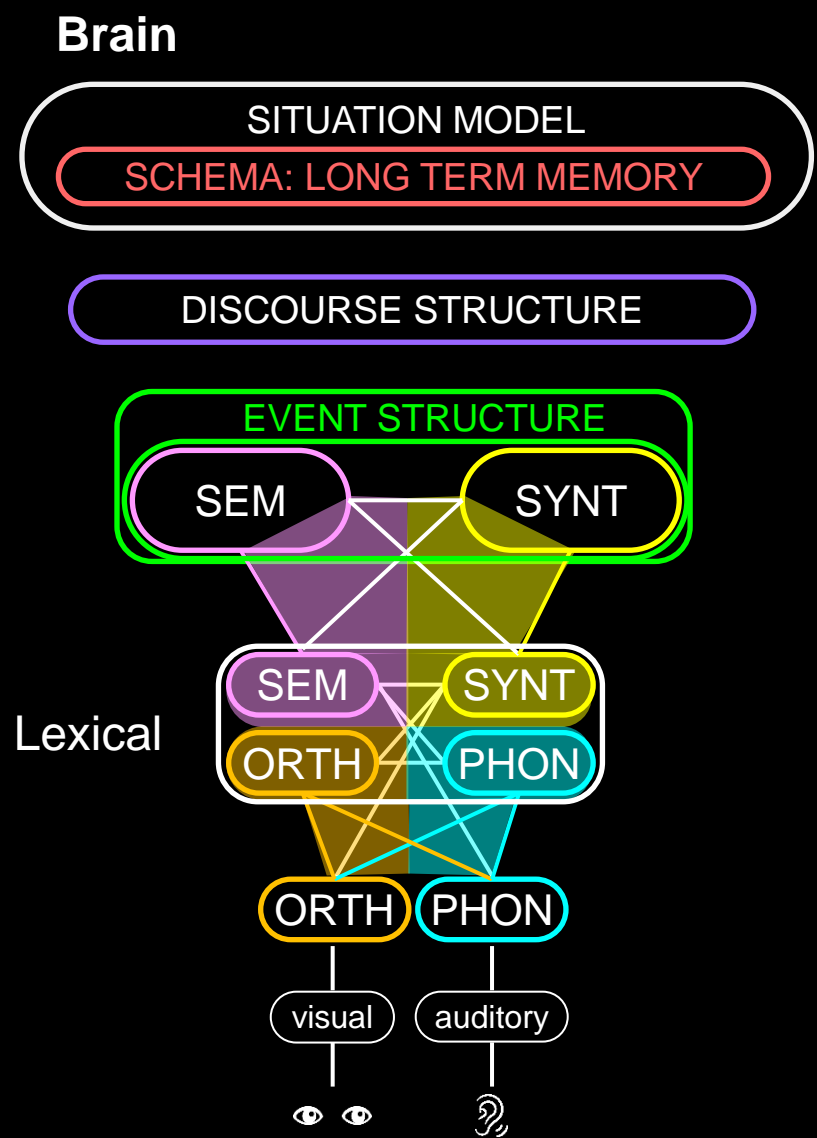
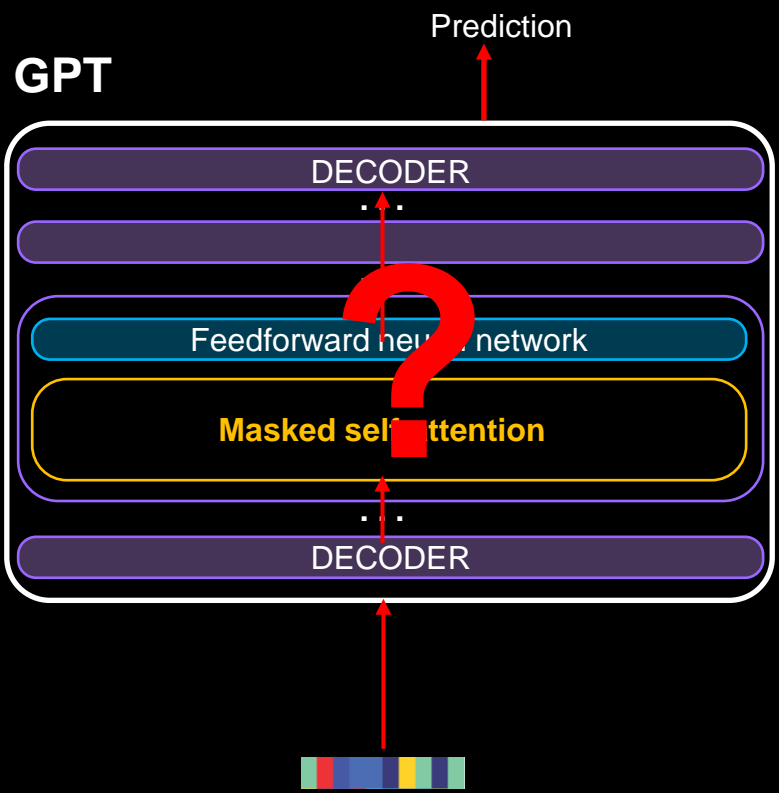


Adapted from Fig. 2
 Roelfsema & Holtmaat, *Nat Rev Neurosci*, 2018

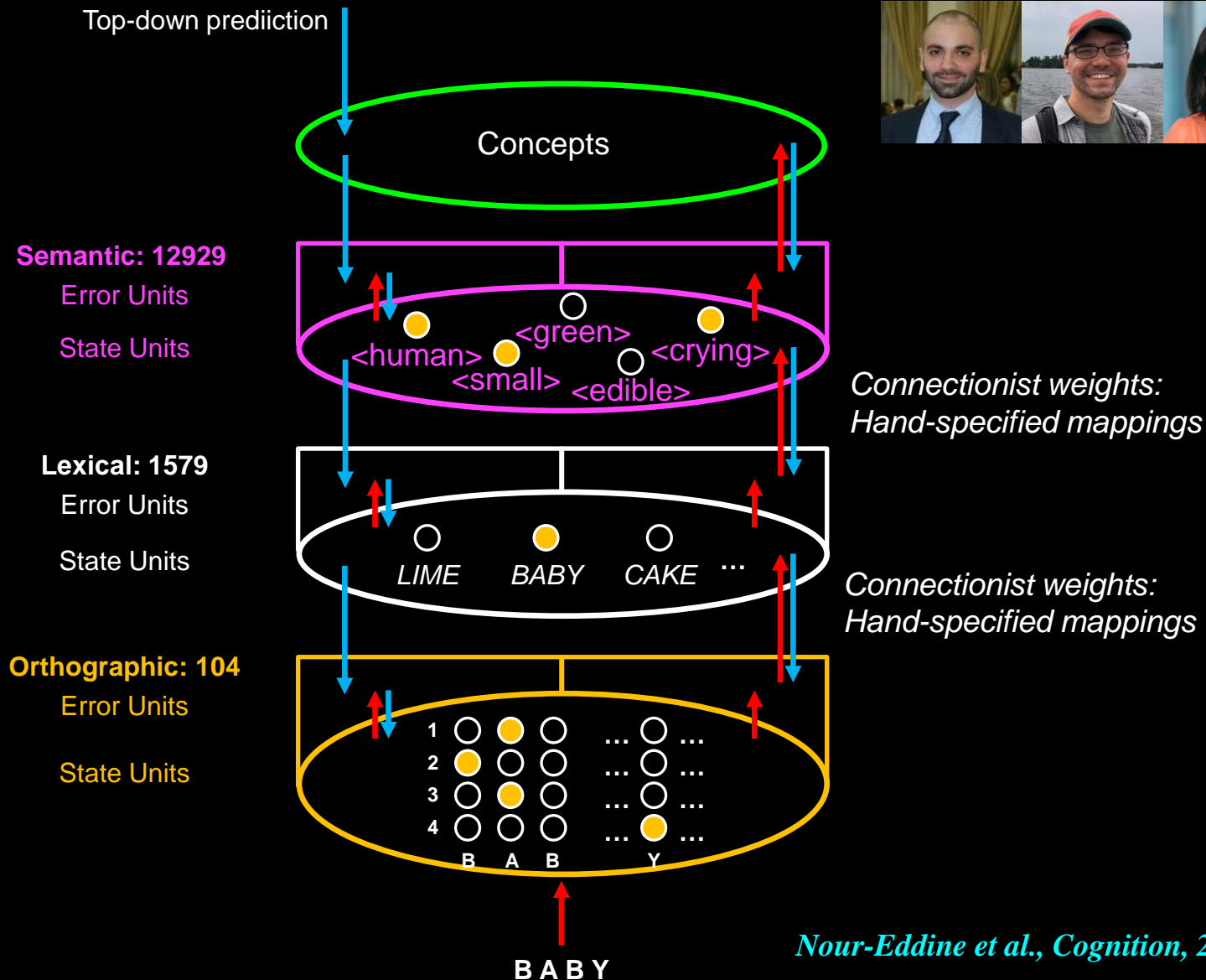
See also: Mumford, *Biol Cybern*, 1992; Bastos et al., *Neuron*, 2012

Most LLM architectures are neither cognitively nor biologically plausible

And remember that the brain is not *trained* to predict!



An implemented (toy) Predictive coding model of Language Processing



Explains bottom-up effects

Psycholinguistically plausible

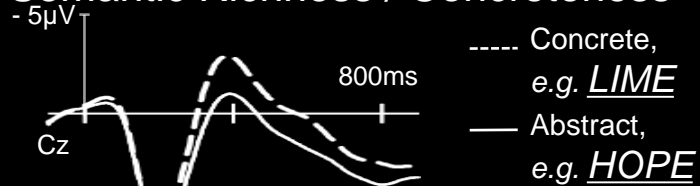
SITUATION MODEL
SCHEMA: LONG TERM MEMORY

DISCOURSE STRUCTURE

EVENT STRUCTURE

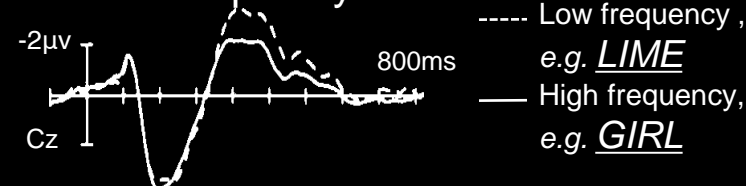
Real Data

Semantic Richness / Concreteness



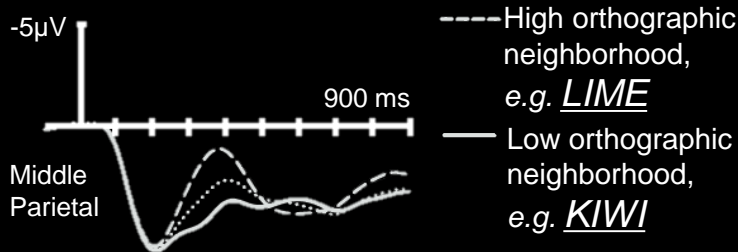
From Lee & Federmeier, *Brain Lang*, 2008

Lexical Frequency



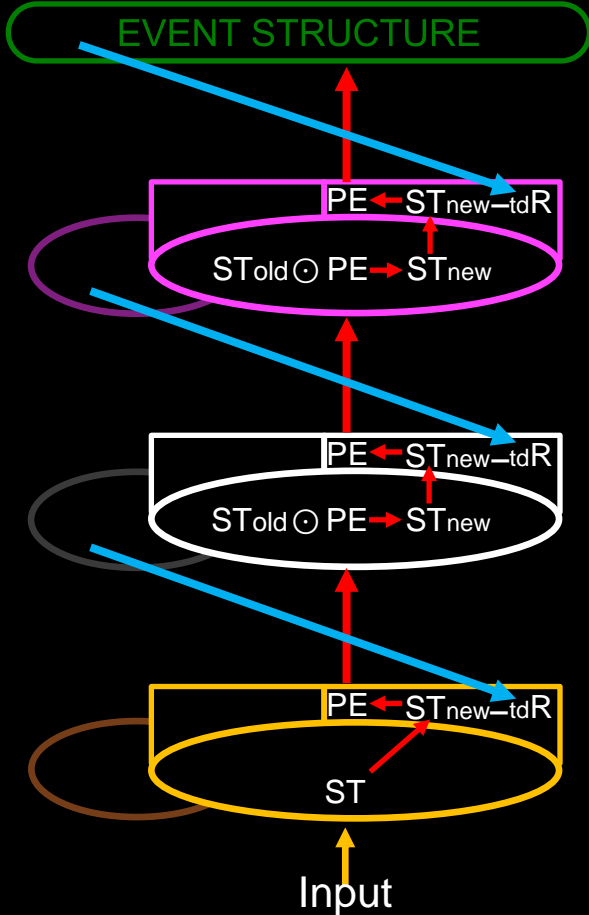
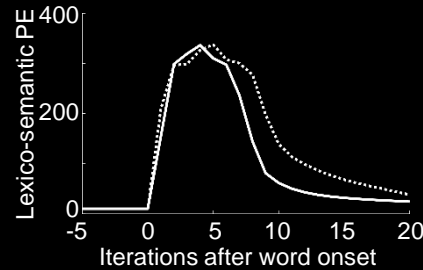
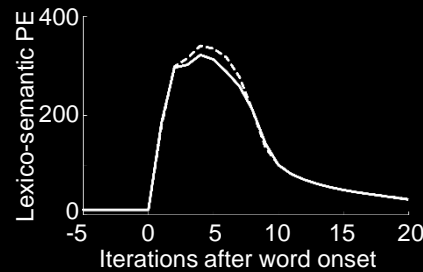
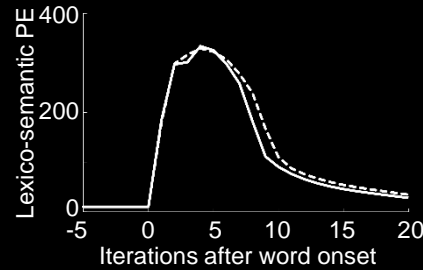
From Van Petten & Kutas, *Mem Cognit*, 1990

Orthographic Neighborhood Size



From Laszlo & Federmeier, *Psychophysiology*, 2011

Simulations



Nour-Eddine et al., *Cognition*, 2024

Explains top-down effects

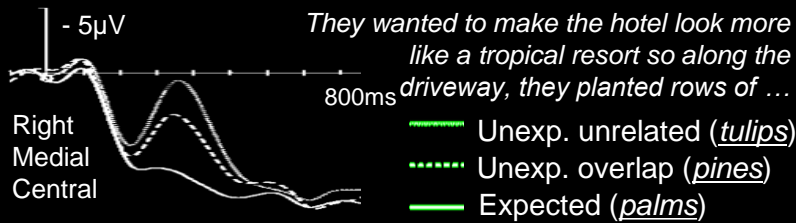
Psycholinguistically plausible

SITUATION MODEL

SCHEMA: LONG TERM MEMORY

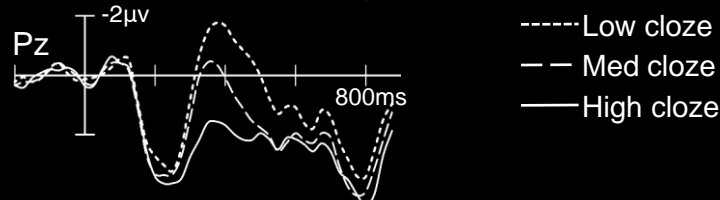
Real Data

Anticipatory semantic overlap effect



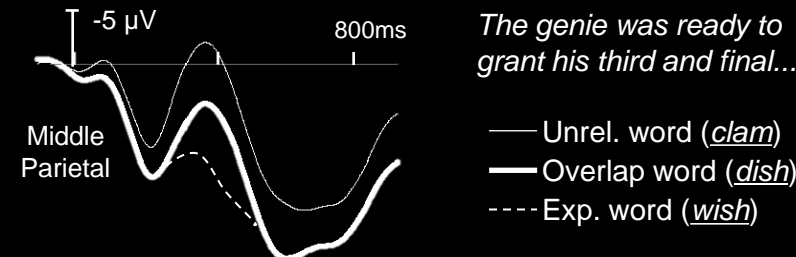
From Federmeier & Kutas, JML 1999

Lexical predictability



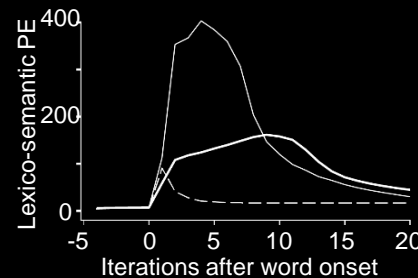
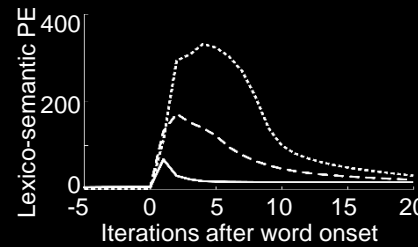
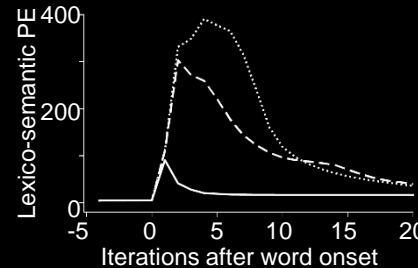
From Brothers, Morgan, Yacovone, & Kuperberg, under review

Anticipatory orthographic overlap effect



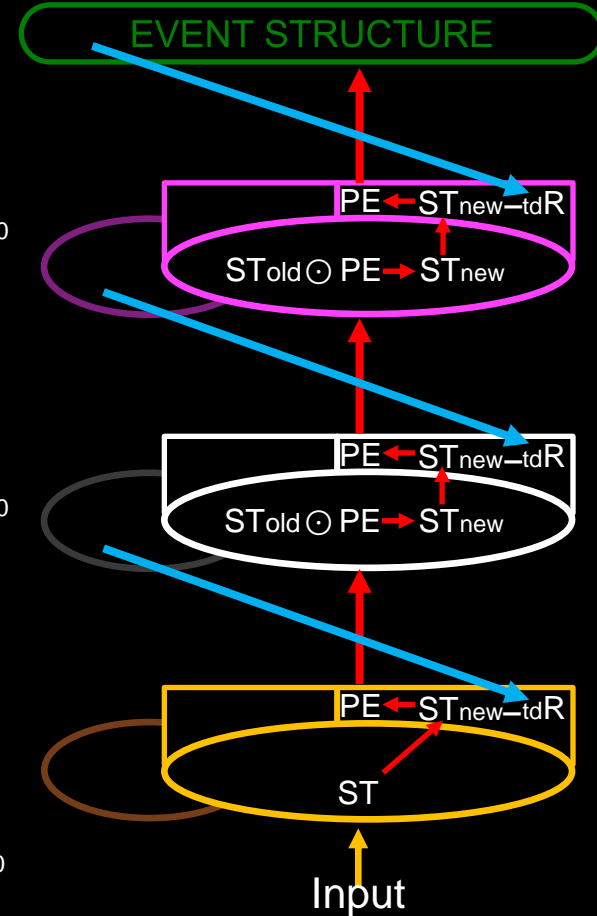
From Laszlo & Federmeier, JML, 2009

Simulations

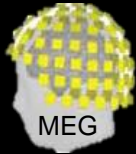


DISCOURSE STRUCTURE

EVENT STRUCTURE



Nour-Eddine et al., Cognition, 2024



Predictive effects localize to regions in left-lateralized temporal lobe that support lexico-semantic processing

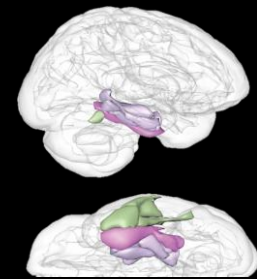
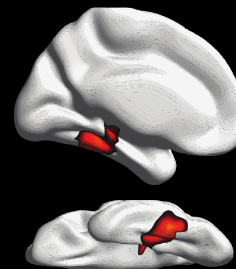
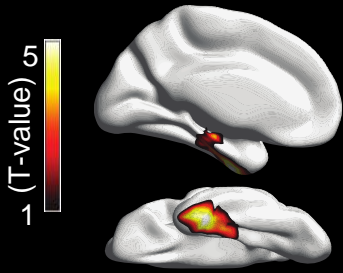


1. N400 effect in plausible sentences localizes to regions of the left temporal lobe that support lexico-semantic processing

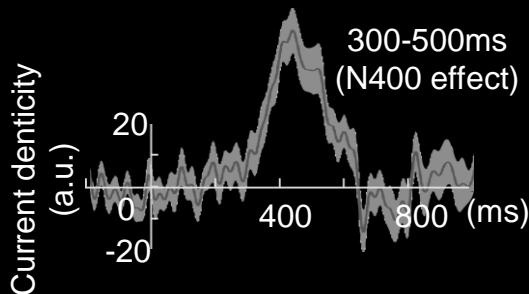
2. In predictive contexts, unique temporal patterns within the left ventromedial temporal lobe encode predicted words *before* new bottom-up input becomes available

3. When expected inputs are encountered, the same item-specific patterns are reinstated within the left ventromedial temporal lobe between 300-500ms

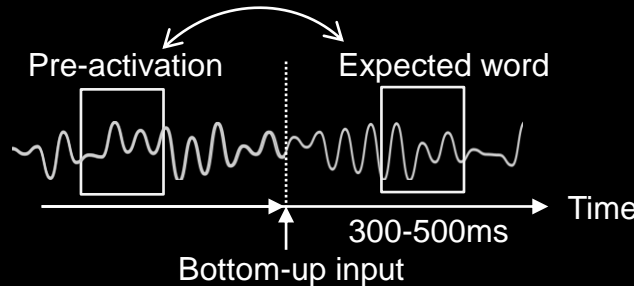
4. Expected inputs produce consistent spatial patterns that are distinct from those produced by unexpected inputs within the left ventromedial temporal lobe between 300-500ms



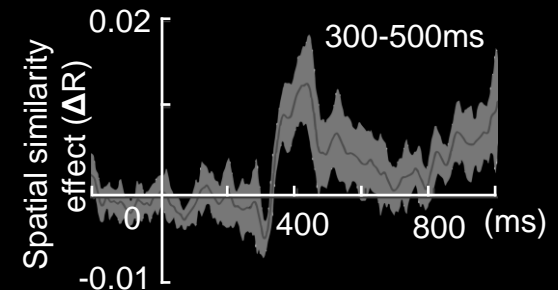
Evoked effect:
Unexpected > Expected



Temporal similarity effects
Within-expected



Cross-trial spatial similarity effect:
Within-expected > Between-condition

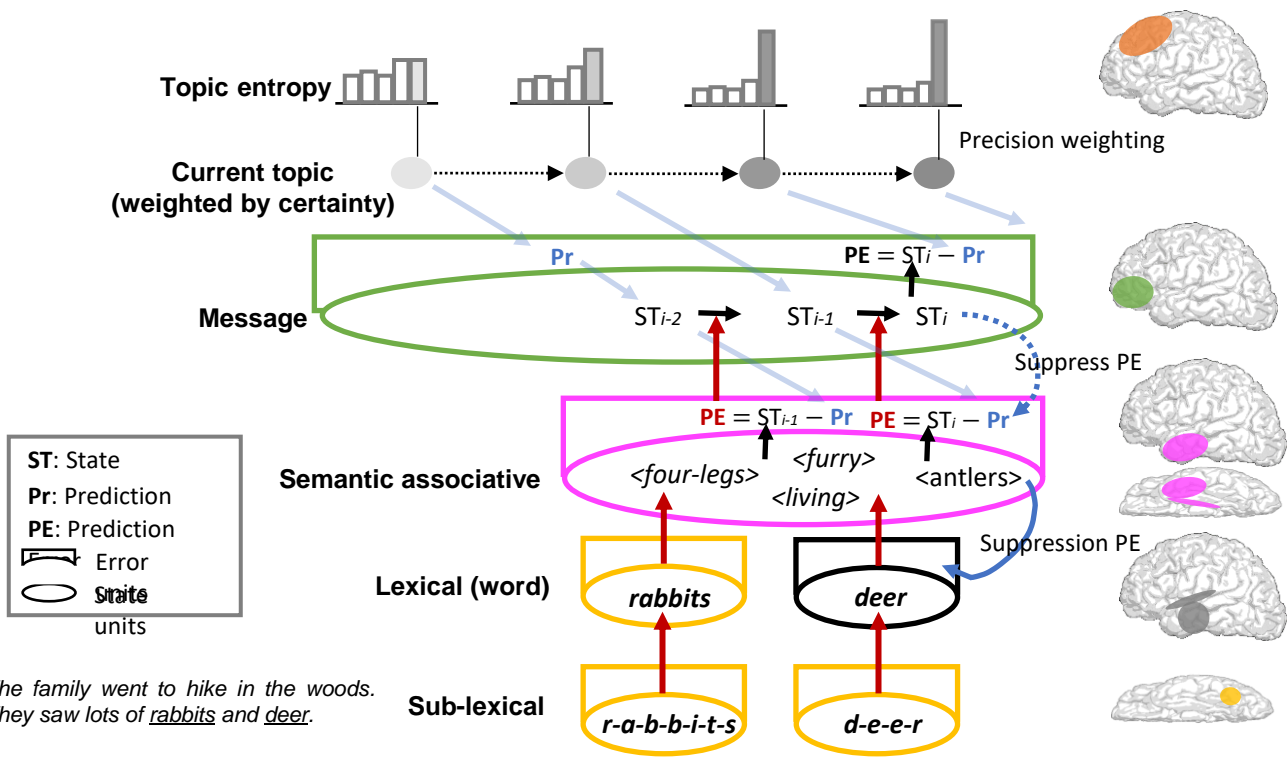


Wang et al., *Cereb Cortex*, 2022

Wang, Kuperberg, & Jensen, *e-life*, 2018

Wang & Kuperberg, *Soon to be submitted!!*

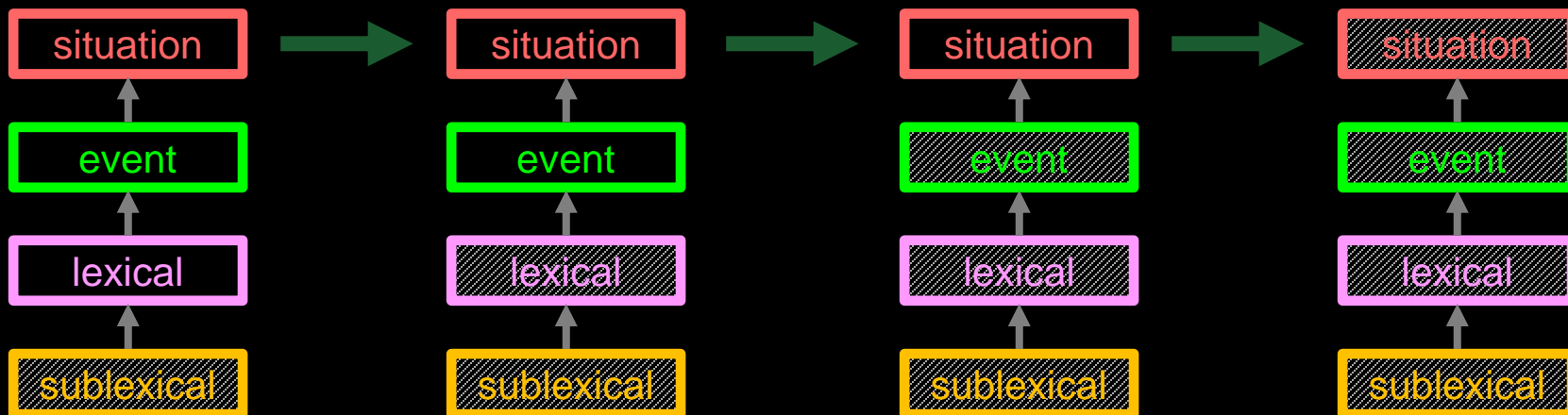
A Neurobiological and Computational Model of Positive Thought Disorder



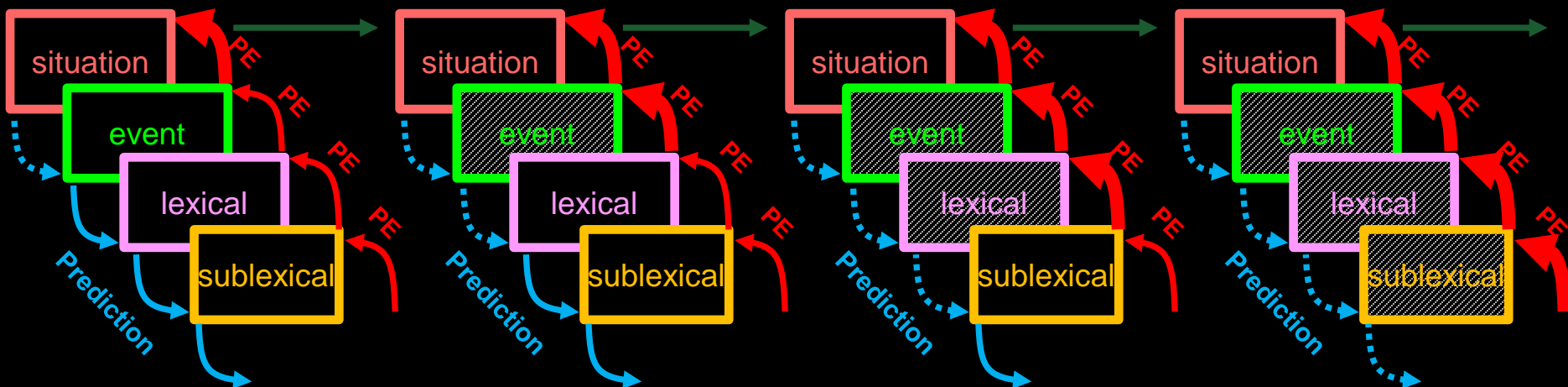
The family went to hike in the woods.
They saw lots of rabbits and deer.

Implications: Relationships between Perceptual and Cognitive Dysfunction in Psychosis

Assumption: Core problem is Perception



Alternative Explanation: ?Failure to to suppress lower-level PE



Summary

- NLP measures can be used to ask specific theoretical questions about levels of representation in psychosis
- BUT their architectures are neither cognitively nor biologically plausible and so they cannot tell us much about the neural and computational *mechanisms* underlying language processing.
- Predictive coding offers a biologically and cognitively plausible architecture and algorithm in which prediction plays a crucial functional role in production, comprehension & learning in psychosis

Where to go?

- Do these findings generalize to more chronic patients; other language protocols??
- Time course???
- Development!
- Linking language production & comprehension
- Interactive protocols!

Thought Language and Communication Interactive!

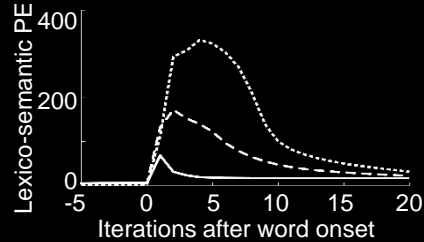
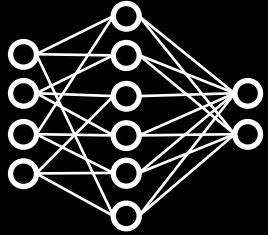
*One could make a case that all of this is ultimately
about implicit pragmatic function*



Thought Language and Communication

Computational modeling

$$P(H) * P(D|H) \propto P(H|D)$$



Comprehender



*In the crib
there was a
little baby*

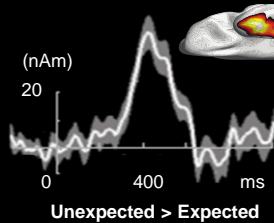
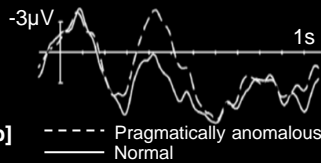
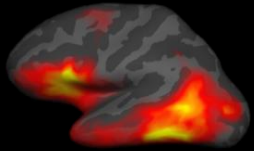
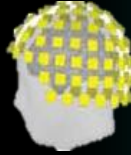


Neuroimaging methods

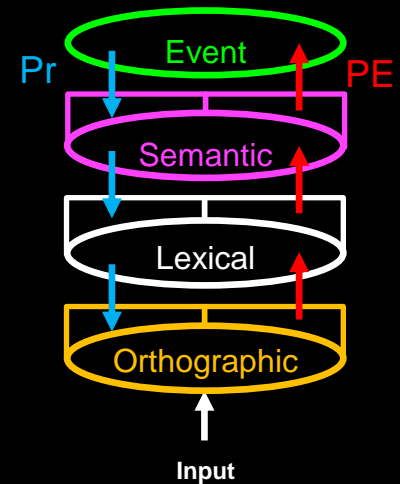
fMRI

EEG/ERP

MEG



Hierarchical Generative Framework Of Language



Statistical techniques

Neuropsychological testing



Clinical & cognitive assessments